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Journal of Experimental Psychology

EDITED BY

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HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
RAYMOND DODGE, YALE UNIVERSITY (*Monographs*)
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*Bulletin*)
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THE RELATION OF INTELLIGENCE AND OF MECHANICAL SPEEDS TO THE VARIOUS STAGES OF LEARNING

BY W. R. ATKINSON

Southwestern, Memphis, Tennessee

INTRODUCTION

In connection with the development of concepts of intelligence questions have arisen as to the relation between intelligence and learning ability. No great amount of agreement can be found among the writers who have generalized on the meaning of either of these terms; and when the relationship between the two is the point in question, we have only a scanty amount of experimental evidence upon which to base definite statements. Ruch [1] has touched upon the problem, and the only additional experimental data that the writer has been able to find appear in an unpublished master's thesis by M. C. Barlow (Library of the George Peabody College for Teachers).

Ruch used three tests of learning ability; card sorting, code substitution and abstract relations. These tests were given to groups of fifty to sixty-five pupils in grades seven to nine. In each learning test the subjects practiced ten days, 15–20 minutes a day. The mental ages of the Ss were measured by the Stanford Revision of the Binet-Simon Scale, and these were taken as the measure of intelligence in calculating the correlation between intelligence and performance during successive practices in the learning tests. On the first practice in card sorting the correlation between intelligence and achievement was positive but not quite reliable ($.31 \pm .085$); in the sixth and seventh practice the correlation dropped to zero, and in the final practices the coefficients were slightly negative. In the code-substitution test the correlation was positive and reliable throughout, varying around $.60 \pm .050$, with no definite trend toward increasing or decreasing from practice to practice. In his abstract-relations

[1] G. M. Ruch, The influence of the factor of intelligence on the form of the learning curve, *Psychol. Monog.*, 1925, 34, (no. 160).

test the correlation between these same two factors was high in the first practice (.72 ± .041) and tended to become higher with continued practice (.82 ± .028 on the tenth). The difference between these last two coefficients was not reliable. Considered as a whole, Ruch's investigation indicates that the closeness of the relationship between intelligence and learning depends directly upon the complexity of the task to be learned and that intelligence is not related to limits of ability in simpler tasks.

While studying the effects of continued practice on group variability, Barlow noted that the correlation between mental age and achievement decreased from practice to practice. He administered three learning tests (card sorting, symbol-digit substitution, and mental multiplication) to twenty subjects. There were twelve practices in card sorting and six in each of the other two tests. Only the card-sorting experiments in the two investigations cited here are comparable, and the resulting conclusions are in agreement. The results obtained in the other four learning tests used by these two investigators show that the problem is complex and will require considerable experimentation before generalizations are advisable.

The original purpose of the present investigation was to find out how well intelligence tests measure the achievement of learners as they advance through successive practices toward their limits of ability in several learning tasks; and, at the same time, to see what relationship 'mechanical speed' bears to achievement in each learning test.[2] Since the original contribution of this paper is confined chiefly to the relation of mechanical speed to achievement in learning, it is necessary to define this term at some length.

As applied to any activity 'mechanical speed' refers to the rapidity with which an organism can execute the fundamental part-activities involved. For example, in card sorting the mechanical speed may be the rapidity with which blank cards can be placed in pigeonholes which bear no symbols, the holes being taken in natural sequence, *i.e.* beginning with the hole at the upper lefthand corner of the box and putting one card in each hole from left to right, tier by tier. In theory no improvement can be made in this function; practically, after several trials, little improvement is found, and when this is compared with the great percentage of improvement made in learning card sorting *per se* it is negligible.

The writer wishes to point out, first, that, as the term is used in this paper, mechanical speed does not refer to any general factor which is operative in any and all learning tasks; on the contrary, one's mechanical speed is probably specific for each activity. As we already know, a simple measure of speed, such as one's reaction time, will not give us a clue to his ability or educability in all kinds of motor activities. Compared with reaction time, mechanical speeds are more complex, more specific for each type of activity, and more subject to the influences of training.

---

[2] The experiments reported in this study were planned and partly carried out before Ruch's monograph was published. The writer wishes to express his gratitude to Dr. Joseph Peterson for advice and criticism freely and frequently given from the inception of his problem to the completion of the manuscript, to those students who served as subjects, and to his wife, Amelia Appleton Atkinson, for help in tabulating and in preparing the manuscript.

Secondly, just as mechanical speeds are not to be considered general factors, they are not, on the contrary, to be thought of as unanalyzable entities. The mechanical speed for card sorting, for example,—measured in the present study by taking the time required for sorting blank cards in natural sequence into pigeonholes which bear no symbols—can be subdivided into several measurable part-activities, such as dealing a deck of cards, moving the hand from left to right along a tier of pigeonholes a fixed number of times, or taking cards from a deck one by one regardless of where they fall. These less complex reactions, included in the mechanical speed of sorting, approach simple reaction time as the ultimate limit of analysis. Although mechanical speeds may be further analyzed, the writer does not hold that a better measure of the relative educability of a subject in a particular task can be obtained from such an analysis. A summation score, secured by timing the subject's responses in all the (rationally chosen) elementary part-activities which compose a mechanical speed, would be desirable if our goal were the measurement of purely innate ability. To get a mechanical speed measure, however, we simply strip the new reaction of its newness and measure the subject's speed in that part of the activity which has been functioning previously. The mechanical speed score is admittedly conditioned by training or environment as well as by heredity. This is merely submitting frankly to the impossibility of separating the factors of heredity and training as they operate in human behavior.

Thirdly, as a factor to be studied in connection with learning abilities, mechanical speed is not posited by the writer as the one and all-important factor. It is possible that 'mechanical accuracies,' such as steadiness of hand, skill in finger movements, and the like, may be more worthy of investigation, especially when quality of handwriting and delicacy of touch in piano playing are the goals of achievement. Nor is either of these two factors set forth as being important enough to draw attention from the more complex problems of the part played in learning by persistency, motivation, interest, etc.

It has been found necessary to create the term 'mechanical speed' in order to avoid confusing this factor with reaction time, 'motor time,' 'motility,' and similar terms. For instance, Ream [3] sought "to measure a basic motor capacity; in particular . . . to plan a test which will call into play simple, related movement, fundamental, native in character and easy to measure, and which will *not* call into play accessory, coördinated, and learned movements." In contrast to 'motility,' mechanical speeds are less simple fundamental part-activities; they are specific rather than general; and they do call into play accessory, coördinated and learned movements. A new reaction is learned by an organism bringing to bear upon it a combination of innate and previously acquired forms of response out of which the new form of response

[3] M. J. Ream, The tapping test; a measure of motility, *Psychol. Monog.*, 1922, 31, (no. 140), *312 f.*

develops. This fact justifies an attempt to measure learning ability on the basis of what the organism is, rather than on the basis of what it might have been. We note at once a danger in this method. Since mechanical speeds are conditioned by training as well as by innate structure, they may be further changed by the experience of the organism after it has been measured. Whether the effects of subsequent training make mechanical measures of speed worthless is a problem for experimentation; we may rationally conclude that the older the organism the less its mechanical speeds will be changed by additional experience. Also we must bear in mind that there are probably clues to learning ability or behavior in general which are yet to be discovered and which are of greater importance than mechanical speeds. The value of this concept can best be determined by the rational and especially the empirical reaction to it of other investigators.

By way of definition, *mechanical speed is the rate at which an organism functions in any activity wherein the native and previously acquired responses are given free play and wherein a minimum of unlearned activity is required.*

Experimental Procedure

Three learning experiments form the basis of this study: card sorting, number-code substitution and number-alphabet substitution. Two intelligence tests were used, the Army Alpha and the Columbia Intelligence Examination for High School Graduates. Mechanical speed measures were obtained in each of the forms of learning studied. After a word about the subjects and motivation, the administration of each test will be briefly described.

The Subjects. The thirty members of a class in educational psychology at Southwestern (Memphis, Tennessee) took part in the two substitution tests, and twenty-one of these, with nine others from the course in general psychology, served as subjects in the card-sorting experiment. The work was done February–May, 1927. All of the subjects who started the substitution tests finished them. When a student was absent from the regular class meeting, the test was taken on one of the intervening days; the amount of data affected by this irregularity is 2.2 per cent. Thirty-seven subjects started the card-sorting test, but the results of seven could not be used. Four of them did not complete the twenty-five practices before the end of the session; two, by error, started sorting the blank cards into the numbered side of the sorting

box in such a way that interference with the learning process developed; and one subject was absent for two weeks during the experiment.

The students used in these experiments made up an unusually heterogeneous group compared with the usual college class. Of the original thirty, seven were seniors, twelve were juniors, nine were sophomores, and two were freshmen. The number of women exceeded the number of men (18 and 12).

The Army Alpha scores of this class range from 74 to 179, the mean being 136.3, the standard deviation, 25.0. With the nine members of the general psychology class taking the place of nine of these subjects for the card-sorting experiment, no marked difference in the distribution of intelligence test scores is noted. The score of 74 is replaced by one of 69; the mean is raised to 140.4, and the standard deviation becomes 23.4.

Motivation. These experiments were taken as a semester project in this course of study. The members of the class, however, had nothing to do with the investigation beyond serving as subjects and having the results of the study reported to them at the close of the semester. The point to be made here is that the constant study of principles of learning, with frequent reference to illustrative material in these experiments, must have affected the results to some extent, probably causing a more rapid learning and a higher final achievement than could be expected from a group which serves more disinterestedly as subjects. The class was informed at the beginning of the course that one purpose of the experiments was, if possible, to add a little to what was already known about educational psychology, and all of the students were interested in the outcome of the investigation. Although the subjects were noticeably more active than in the usual college class under the lecture method, there was no evidence of a degree of motivation higher than that of a well-conducted high school recitation.

As a more definite form of motivation, the experimenter showed each subject individually his weekly progress in the form of a learning curve plotted from his data. Each graph contained two curves, one for the learning task and the other for mechanical speed in the assigned task. The subjects were instructed not to communicate with each other at any time in regard to their achievement. The extent to which this instruction was followed cannot, of course, be measured accurately. But the knowledge of the results of others could not seriously affect the performance of any one subject because each member of the class took as his particular goal his own mechanical speed score in that test. When the subjects pointed out that they could not be expected to reach the limits set by the mechanical-speed curves, they were told that they would be ranked on the basis of their approximation to that limit.

Card-Sorting

The method used here does not greatly differ from the usual card-sorting experiment, except for the fact that the learning extended over twenty-five practices, seventy-five trials,[4] covering a period of nine weeks.

The sorting-box contained thirty pigeonholes 3 in square and 4 in deep, arranged in five tiers of six holes each. On one side of the box the holes were not numbered; on the other side they were numbered from eleven to forty-one in the order used by

[4] The term *trial* signifies a separately timed exercise in which the task or unit of work is gone through once; a *practice* is a group of trials completed in succession on any one day.

Pyle.[5] The sorting cards were 2½ by 3½ inch and made from 120-pound paper. There were two kinds of decks, those with cards numbered from 11 to 41, and decks of blank cards. The numbered decks contained five cards of each number, or 150 cards per deck; the blank decks were identical except for the omission of the numbers. The subjects were instructed uniformly by a typewritten sheet of directions. A stop-watch was used for timing. In view of the fact that the experiment was explained in detail to the class and that the directions were at hand at all times, it was not deemed advisable to give a preliminary practice.

On this test the subjects worked in pairs, one sorting while the other kept time and shuffled a deck of numbered cards. At each practice five distributions were made by each subject, the first and last being a distribution of the blank cards into the blank side of the box, beginning each time with the upper lefthand corner and ending with the lower righthand corner until the 150 blank cards were all used. This gave the scores for mechanical speed. The three other distributions consisted in sorting the numbered decks into the numbered pigeonholes. The time-score for each practice is the average of these three trials, expressed in minutes (two decimal places). The mechanical-speed ranks are based on the mean speed of sorting blank cards.

The subjects recorded their time on prepared blanks which contained a space for remarks. The experimenter collected these records every day, taking them from a sealed box in which they had been deposited by the subjects at the end of each practice. Through these remarks it was discovered that the decks varied in efficiency, being somewhat stiff and slow at first, then working well for a few weeks, and then becoming too much worn to work smoothly. To take care of this deterioration of materials a large number of decks was employed and the subjects were instructed to choose each day the kind of deck they thought they could handle most rapidly. Altogether nineteen decks were used. The writer visited the card-sorting room as many as three times a day; and once each week he checked over all the decks, removing any that seemed noticeably worn.

In regard to errors, *i.e.* getting a card in the wrong hole, it was observed by the writer, who went through a number of trials before starting the subjects, that this matter took care of itself sufficiently well for the purposes of this investigation. The instructions provided for the correction of all errors observed during the course of one sorting. That is to say, when a subject saw that he had put a card in the wrong hole he was required to take it out and put it in the proper place, whether he noticed it at the time the error was made or later during the same distribution. If two cards on the same number appeared in succession in the deck, the second was to be placed under the cards still remaining in the subject's hand. This caused a sufficient loss of time to stimulate the careful shuffling of a deck before a sorting was commenced. The experimenter in his own sorting made fewer than one per cent of errors during the first four practices and none thereafter. This refers to errors which are unobserved until the cards are taken out of the pigeonholes at the end of a trial.[6]

In addition to the mechanical speed of sorting blank cards, a score on the Healy coördination test was obtained. This

[5] W. H. Pyle, *A laboratory manual in the psychology of learning*, Baltimore, 1923.

[6] One may reasonably hold that the learner is automatically penalized for errors in card sorting and similar activities since errors delay the learning of the task by developing interference to the correct response, and that to correct a time score on the basis of errors is to inflict a double penalty.

test consists of a sheet containing 150 squares. The subjects were asked to make a dot in as many squares as possible between the signals 'Go' and 'Stop.' The test was given twice for periods of 30 sec at each trial. The ranks used are based on the combined score of the two trials. The Army Alpha scores were taken from the files of the Psychology Department. Twenty-one of these thirty subjects were in the group which took the Columbia Intelligence Examination for High School Graduates; the correlations between this test and achievement in card sorting are based, therefore, on only twenty-one cases, whereas all other correlations involve thirty.

Number-Code

This substitution test is taken from Averill's *Elements of educational psychology* (p. 64). A diagram which consists of two parallel vertical lines intersecting two parallel horizontal lines was drawn on the board and the numbers 1 to 9 were written into the figure.

At the side, 'o' was symbolized by an 'X'. The subjects were shown how they could write in code any number they wished by using X for o and by using the adjacent parts of the diagram for the first nine digits. By way of illustration several numbers were written on the board in code. (][= 28; LX = 70.) The subjects were instructed to begin with 1 and write in code as far as they could before time was called. They had three trials of two minutes each on every practice day (Mon., Wed. and Fri. at 10 A.M.).

This test was continued twenty days. A glance at the mean scores in Table II will show that apparently the limits of ability had not been reached. In card sorting the difficult factor to control was the deterioration of the material. In the experiment under discussion, the quality of the written responses presented a difficult problem. The more rapid the performance in the test, the less neat the written product became; but at no point in the work of any individual can we draw the line between the satisfactory and the unsatisfactory quality of work. To require the same standard of quality of all subjects would be as impossible as to require the same speed of response. To require of each the same quality of writing that he has employed in other written work is to penalize the careful writers and to give advantage to the

careless. The writer could think of no better requirement than the one just mentioned, however, and he instructed the subjects to keep the quality of their work as near as possible to that of their other daily writing. The extent to which this requirement was met cannot be accurately measured. Toward the end of the twenty practices the papers were definitely inferior in quality to those turned in for earlier practices. Evidently a continuation of the exercise beyond twenty days would have resulted in greater achievement in quantity at the expense of quality of work. On the last three practices the experimenter inspected the responses of all subjects whose work was deteriorating in quality and made sure that each one could translate readily some of his own symbols picked at random.

The achievement scores obtained in this test consist of the average of the three trials for each day. An inspection of the papers shows that the number of errors made is so small that the scores, if corrected, would not be changed .5 of 1%; that the quick learners make as large a percentage of errors as the slow learners, and that after the first three practices no errors are likely to occur. Therefore, since the records contain 90,000 responses, no attempt has been made to count all the errors. Each subject worked, however, with the understanding that each wrong response would count against him.

On the first day the experimenter measured the mechanical speed of writing of these thirty subjects. Each was given a sheet of paper and a sharpened pencil with directions to start with "1" at the signal *Go*, and to write as many Arabic numerals as he could before time was called. Three one-min trials were given. This procedure was repeated once each week and the average of the seven weekly scores is the basis for the mechanical-speed ranks for writing numbers. Another measure of mechanical speed was taken in connection with the number-alphabet test, to be described presently; the results were used also in studying the achievement on the number-code test.

The Army Alpha scores of these students were taken from

the files of the Department. At the end of the semester these subjects were given the Columbia Intelligence Examination for High School Graduates; the forms used were Part I, P, 1920; Part II, J, 1921; and Part III, P, 1922.

Number-Alphabet

After an interval of one week the same thirty subjects began this second substitution test, which is adapted from Peterson's experiment described in "Limits of Learning by Trial and Error."[7] Using Peterson's pairing of the letters of the alphabet with the twenty-six numbers, the writer converted the experiment into a group test with 1,000 stimuli printed in blocks of 100 on $8\frac{1}{2} \times 11$ inch paper.

The key is written across the top of the sheet and the rest of the page consists of columns of numbers (11 to 36) in random order. The subjects are required to write the correct letter beside each number, referring to the key whenever necessary. Ten trials of one minute each constituted a day's practice, and the learning was continued through twenty-one practices (seven weeks). The average of the ten trials per day is the score used in working up the results.

To obtain a mechanical-speed measure for this learning test, the writer duplicated a form which contained 200 letters of the alphabet arranged in random order in columns similar to those of the learning test. The subjects merely copied these letters as rapidly as they could. This activity was the same as that of the learning test, except for the fact that no learning was involved. The scores from this test are based on the average of the seven weekly trials. The mechanical-speed records show a 25 per cent increase whereas the scores in the learning test increased 750 per cent.

In previous work, while searching for significant factors of intelligence, the writer measured speed of subvocal counting and found the scores surprisingly reliable, though not valid for revealing general ability. Since the number-alphabet test involves, especially at the beginning, more ideational and less sensori-motor characteristics than the number-code test, the speed of subvocal counting was measured with a view to discovering whether this mechanical type of response is related to achievement in a test involving associative learning. The subjects were instructed to begin with 1 and to "count to themselves," reducing lip, tongue and laryngeal movements to a minimum. After a short preliminary practice they were timed for three periods of 10 sec and one period of 30 sec. At the end of each period they recorded the number to which they had counted. No communication of results was permitted until the records had been collected. Obviously this measurement is defective. There is no way to control skipping or slurring of numbers, nor can the scores recorded be considered wholly objective. The high reliability coefficient ($.91 \pm .02$) and the similarity between the mental processes involved in this task and in the learning test under consideration are the only justification for including these data in this study. Since the response required in the learning test is written, this subvocal counting cannot be said to be more than a partial mechanical-speed measure for the number-alphabet test.

[7] This JOURNAL, 1926, 9, 45–55.

As in the number-code substitution, the problem of quality of response had to be solved. The subjects were instructed to write well enough to be able to read their own responses, and the experimenter checked this during the last five practices, finding that all subjects could read their own work. This method of checking is not entirely satisfactory since the number from which the letter was derived is before the subject and he could get the correct letter by association if he could

TABLE I

CORRELATION OF ACHIEVEMENT IN EACH OF TWENTY-FIVE PRACTICES IN CARD SORTING WITH (1) ACHIEVEMENT IN THE NEXT PRACTICE PERIOD, (2) ARMY ALPHA, (3) COLUMBIA INTELLIGENCE EXAMINATION (21 Ss), (4) SPEED OF SORTING BLANK CARDS, AND (5) HEALY COÖRDINATION TEST. THE MEAN GROUP-ACHIEVEMENT SCORE, WITH THE STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY, IS GIVEN FOR EACH PRACTICE

	(1)	(2)	(3)	(4)	(5)	Additional Data		
		Intell'ce Tests		Mechanical Speeds				
Practice	Next pract.	Alpha	Col.	Sorting	Co-ord'n.	Mean Scores	S. D.	Coeff. of Var'ty.
1	.63	.39	.12	.07	.35	13.70	1.84	.134
2	.84	.04		.20	.04	9.33	2.17	.232
3	.82	.10		.17	.04	6.80	1.56	.229
4	.91	.00		.26	.18	5.50	1.26	.230
5	.90	−.01	.00	.17	.18	4.83	1.05	.217
6	.88	−.10		.30	.26	4.26	.85	.199
7	.84	.00		.30	.15	3.92	.71	.180
8	.88	−.04		.27	.30	3.81	.69	.181
9	.77	−.08		.34	.24	3.57	.58	.162
10	.88	−.08	−.08	.36	.39	3.41	.62	.182
11	.84	−.03		.21	.36	3.42	.52	.154
12	.84	.10		.23	.34	3.26	.48	.147
13	.76	−.05		.33	.30	3.18	.52	.165
14	.86	.06		.46	.35	3.08	.48	.156
15	.92	−.05	−.20	.41	.33	3.06	.42	.138
16	.87	.08		.44	.33	3.05	.48	.159
17	.86	.08		.48	.28	3.00	.47	.158
18	.91	.11		.44	.34	2.95	.51	.174
19	.91	.08		.45	.42	2.88	.48	.168
20	.91	−.04	−.25	.50	.37	2.83	.45	.160
21	.86	−.03		.52	.30	2.76	.38	.138
22	.91	−.05		.63	.39	2.68	.39	.145
23	.92	−.02		.50	.34	2.66	.38	.142
24	.84	−.04		.46	.34	2.59	.33	.126
25		.04	−.06	.41	.34	2.51	.36	.143

not read his own writing. The speed with which the subjects could read their responses, however, indicated ability to read their writing. Regardless of deterioration in quality we may rest assured that the subjects knew what letter they were writing when they wrote it.

Results

Tables I, II, and III give the results obtained from an analysis of the data of the three learning tests just described. The rank-difference method of correlation has been used for ascertaining the relationship between scores in learning, intelligence, and mechanical-speed tests. Where thirty cases

Table II

Correlation of achievement in twenty practices in the number-code test with (1) achievement in the next practice period, (2) Army Alpha, (3) Columbia Intelligence Examination, (4) speed of writing numbers, (5) speed of subvocal counting. The mean group-achievement score, with the standard deviation and coefficient of variability, is given for each practice

	(1)	(2)	(3)	(4)	(5)	Additional Data		
		Intell'ce Tests		Mechanical Speeds				
Practice	Next pract.	Alpha	Col.	Writing	Counting	Mean Scores	S. D.	Coeff. of Var'ty.
1	.84	.70	.29	.30	.24	19.5	5.58	.286
2	.94	.51	.12	.46	.33	26.5	5.97	.226
3	.95	.42	.04	.65	.40	30.9	6.35	.220
4	.97	.36	.00	.70	.44	34.4	7.19	.209
5	.97	.53	.10	.68	.48	37.1	9.29	.196
6	.96	.55	.13	.74	.51	39.3	7.89	.201
7	.96	.47	.12	.76	.51	42.6	8.65	.203
8	.97	.41	.03	.77	.56	43.9	8.34	.189
9	.98	.48	.05	.74	.56	45.9	9.10	.181
10	.98	.50	.08	.74	.57	48.4	9.66	.197
11	.97	.50	.07	.77	.59	48.9	9.84	.201
12	.96	.52	.04	.75	.57	50.3	9.64	.191
13	.99	.50	.06	.79	.61	52.4	9.77	.186
14	.98	.45	.01	.78	.57	53.4	9.64	.180
15	.95	.40	−.02	.76	.57	53.3	9.94	.187
16	.98	.45	.01	.78	.61	54.8	10.48	.191
17	.98	.48	.04	.81	.65	56.3	10.61	.188
18	.98	.40	−.04	.81	.61	57.4	10.52	.183
19	.99	.50	.03	.83	.65	59.3	11.26	.190
20	.00	.49	.03	.83	.66	61.3	11.97	.193

TABLE III

CORRELATION OF ACHIEVEMENT IN EACH OF TWENTY-ONE PRACTICES IN THE NUMBER-ALPHABET TEST WITH (1) ACHIEVEMENT IN THE NEXT PRACTICE PERIOD, (2) ARMY ALPHA, (3) COLUMBIA INTELLIGENCE EXAMINATION, (4) MECHANICAL SPEED OF WRITING LETTERS OF ALPHABET, (5) MECHANICAL SPEED OF SUBVOCAL COUNTING. THE MEAN GROUP-ACHIEVEMENT SCORE, WITH THE STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY, IS GIVEN FOR EACH PRACTICE

	(1)	(2) (3) Intell'ce Tests		(4) (5) Mechanical Speeds		Additional Data		
Practice	Next pract.	Alpha	Col.	Counting	Writing	Mean Scores	S. D.	Coeff. of Var'ty.
1	.90	.26	−.08	.41	.09	17.6	3.05	.176
2	.92	.21	−.03	.28	.05	21.6	4.20	.195
3	.94	.17	−.05	.44	.12	25.7	6.41	.249
4	.92	.10	−.03	.42	.12	27.7	8.44	.308
5	.95	.04	−.04	.43	.22	36.6	9.39	.257
6	.96	.08	−.07	.44	.32	43.4	12.73	.293
7	.95	.15	.06	.42	.37	51.4	14.77	.289
8	.97	.16	.09	.40	.42	57.6	15.96	.287
9	.98	.17	.12	.39	.41	65.8	16.56	.252
10	.98	.14	.11	.42	.42	72.9	17.14	.235
11	.97	.15	.12	.46	.45	78.8	17.22	.219
12	.98	.17	.07	.54	.45	83.9	17.68	.211
13	.98	.21	.15	.59	.48	90.1	19.00	.211
14	.97	.24	.14	.59	.50	94.4	20.17	.214
15	.97	.28	.16	.60	.48	97.6	19.01	.195
16	.96	.23	.13	.59	.48	102.1	20.37	.199
17	.96	.30	.13	.65	.54	105.9	21.17	.200
18	.97	.27	.13	.64	.48	108.7	21.83	.201
19	.97	.29	.10	.66	.54	114.0	23.69	.208
20	.96	.25	.11	.64	.53	117.3	23.23	.198
21		.24	.18	.68	.50	121.0	24.12	.199

are concerned, a coefficient of .40 is four times its probable error. It will be observed that many coefficients in the tables are lower than .40. In these cases we hold, of course, that no reliable positive relationship is established between the two functions correlated. But, for the purposes of this study, the reliability of the coefficients is not as important as the trend upward or downward that a series of coefficients shows. Consistent increase or decrease in the size of the coefficients is evidence that, as practice continues, the two functions con-

cerned are becoming more or less closely related. The three tables include also the mean achievement scores for each practice, together with the standard deviations and the variability coefficients. The problem of variability is to be discussed in the next section.

Additional facts which cannot be conveniently included in the tables are here given:

Reliability Coefficients	
Sorting blank cards	.96
Speed writing letters	.89
Speed writing numerals	.94
Subvocal counting	.91
Healy coördination	.95
Army Alpha	.82

Correlation between Mean Scores and Standard Deviations	
Card sorting	$.96 \pm .01$
Number code substitution	$.97 \pm .01$
Number alphabet substitution	$.99 \pm .00$

Correlation between	
Alpha and Columbia tests	.60
Alpha and writing letters	.28
Alpha and writing numerals	.44
Alpha and subvocal counting	.37
Alpha and sorting blank cards	−.23
Alpha and Healy coördination	.22
Writing letters and numerals	.86
Subvocal and written numerals	.66
Subvocal counting and writing letters	.67

The fact that a close relationship exists between the mean achievement scores and the standard deviations for the successive practices in each test (as shown in the tables) indicates a high degree of homogeneity in difficulty throughout each learning process. This condition assures us that we are dealing with a single learning process in each experiment and, at the same time, limits the application of our results to such learning tasks.

When we inspect Tables I, II and III, we note that the correlation of achievement in each practice with achievement in the following practice is high. In card sorting the average of these coefficients is $.86 \pm .04$; in the number-code test the average is $.97 \pm .01$; and in the number-alphabet test the average is $.96 \pm .01$. This means that the changes in ranking among the subjects during the learning of these tasks come about gradually rather than suddenly at some particular stage of the learning process. We may hold, therefore, that, whatever changes occur in the relations of intelligence and mechanical speed to achievement, those changes are not due to an unevenness in difficulty of the tasks at various stages, nor

do they take place in any particular practice or small group of practices.

What the data show with regard to the relation of intelligence to achievement in different stages of learning may be now examined. First, in the card-sorting test, both tests of intelligence measure initial performance better than intermediate or final achievement; neither intelligence test reveals limits of learning ability in this task. Secondly, in the number-code test both intelligence tests seem to yield the same results as in card sorting, but no reliable difference is found in the relation of intelligence to achievement between the first and last five practices. A similar result was obtained by Ruch with his code-substitution test.[8] Ruch ascribes this constancy in relation of intelligence to achievement in successive practices to the relative complexity of the test. We have no objective criteria of the relative complexity of tests. Rationally considered, the number-code test is more complex and more ideational (as opposed to sensori-motor) than card sorting. Thirdly, in the number-alphabet test the relationship between intelligence and achievement remains stationary or tends to become closer, depending upon which intelligence test is taken as the criterion. Ruch obtained increasing coefficients when he correlated performance in his abstract-relations test with mental age, but the difference between the coefficients of the first and last five practices is not reliable. The number-alphabet test is thought to be the most complex of the three used in the present investigation; whereas Ruch's abstract-relations test is his most complex, and it is obviously more complex and more ideational than the number-alphabet test just referred to.

In general, then, we find no simple, definite trends among the coefficients obtained from correlating intelligence with achievement under practice in the tests employed in the present study. The results indicate that intelligence tests measure initial performance in simple tasks only moderately well but do not measure later achievement or limits of ability at all. As learning tests of increasing complexity are con-

[8] *Op. cit.*, p. 35.

sidered, we find the problem complicated and the results varying to such an extent that we must leave the matter open for further investigation. The tests used in this study were not selected for the specific purpose of showing the effects of complexity of the learning process on the relation of intelligence to learning abilities, and the tests do not by chance have a sufficient range of complexity to reveal such effects clearly. While Ruch's results agree with those stated here, the present writer does not see in the results of either study sufficient evidence upon which to base definite statements in regard to the relationships under consideration. Our data merely indicate an increasingly close relationship of intelligence to learning abilities with increasingly complex learning-tasks. The strength of this statement is in its weakness—in its tentative nature; it says all that the data justify.

The relation of mechanical speed to achievement is more simple and clear. In the three experiments employed in this study, mechanical-speed tests are superior to intelligence tests in revealing capacity to learn the particular tasks presented. This superiority becomes evident early in the learning process and increases with continued practice. The mechanical-speed tests which are most closely related to the fundamental activity involved in the learning process are apparently the real measures of limits of learning ability in those tasks. The fact that this superiority of the mechanical-speed tests is not, in general, present during the initial performances on the learning tests is a phenomenon which stimulates one to speculate as to the nature of the interrelations of intelligence, mechanical speeds and learning abilities. Such speculations are appropriately confined to a separate section.

Variability of the Group as Affected by Continued Practice

This problem has been studied in numerous investigations. An excellent summary of the experimental evidence up to the present time has been given by Peterson and Barlow [9] in an

[9] J. Peterson & M. C. Barlow, Effects of practice on individual differences, *Yearbk. Nat. Soc. for the Study of Educ.*, 1928, 211–230.

article which contains, in addition to their own results, a valuable discussion of the technical difficulties involved. Roughly speaking, in twenty-four studies by various investigators it has been found that the subjects become more alike under continued practice; the results of three studies either do not permit conclusions or show no change in variability; while seven investigations show a tendency for the subjects to become more unlike. The joint authors referred to above call attention to the likelihood that the complexity of the function practiced is an important factor in determining whether convergence or divergence will be found. It is their belief that, in general, subjects become more alike in the simpler activities and more unlike in the complex activities; and they add, by way of caution, that many of the processes which we have been accustomed to call 'complex' could probably be classified better as 'simple.'

The data from the three learning experiments used in this study have been shown in Tables I, II, and III in the form of variability coefficients obtained by dividing the means by the standard deviations. In ordér to obtain some measure of the validity of this method, the coefficients of correlation between the means and the standard deviations have been calculated by the rank difference method.[10] A high correlation in this particular signifies homogeneity in difficulty throughout the learning process and a constancy in the location of the zero-point. A low correlation shows the opposite condition. In the latter case a comparison of the variability coefficients from practice to practice is of little value. The following high correlation coefficients between means and standard deviations seem to justify our method:

Card sorting ..... .96 for twenty-five practices
Number-code substitution ..... .97 for twenty practices
Number-alphabet substitution ..... .99 for twenty-one practices.

In order to show more definitely the changes in variability, several groups of practices may be considered together as follows:

[10] Cf. Peterson & Barlow (*op. cit.*) as to the significance of this correlation.

THE PRACTICES AVERAGED	THE LEARNING TESTS		
	Card-sorting	Number-code	Number-alphabet
First five	.209	.227	.237
Last five	.139	.190	.201
First ten	.195	.211	.254
Last ten	.151	.192	.205

In all three learning tests it is to be observed that the subjects are more alike on the last five practices than on the first five, and more alike on the last ten than on the first ten practices. The actual differences are at least four times the probable error of the differences in all cases except between the first and last five practices of the number-alphabet test and the first and last ten practices of the number-code test, in which the actual differences are, respectively, 2.8 and 3.3 times the probable error of the difference.

A glance at the complete tables will show that this convergence is by no means steady and constant; yet, in the final practices where the subjects are approaching their limits of ability, the data point definitely toward convergence.

In card sorting and number-alphabet substitution the subjects are more alike in initial achievement than they are at almost any other stage of the learning process; but they become more unlike in the second or third practice, after which the tendency is to converge throughout the remainder of the test. If one were to base conclusions on data obtained from a few practices, *i.e.* a partial learning, one would conclude that in the number-alphabet test the students become more alike with continued practice. Some investigations of this problem have extended over such a small part of the learning process as to justify the view that the resulting conclusions might be reversed if the experiments were continued through twice as many practices.

The different trends of these successive variability coefficients in the three learning experiments challenge an explanation. In the card-sorting test the only anomaly is the first practice, wherein the subjects are more alike than in any other practice that follows except the twenty-fourth. Yet from the second practice to the last there is a constant tendency for the coefficients to decrease. The writer has no explanation to

offer for the first variability coefficient. To say that it is due to the unusually large mean for the first practice coupled with a small standard deviation is to go counter to the statistical method upon which this part of the investigation is based; and to discard the data of the first practice, claiming it was a first practice, is to be unscientific.

In the number-code experiment a rather steady decrease in variability of the group is to be noted. Here the task is to learn to make ten unknown symbols as substitutes for ten well-known numbers. Nothing new enters into the learning process, and developing these ten associations is a rather simple task as compared with the number-alphabet test which consists of twenty-six associations. This latter activity is more of the nature of mental multiplication, abstract relations, and similar complex or ideational tests in which previous investigators have found a tendency toward divergence. The increase in variability which is followed by a decrease can be explained by the nature of the learning process involved.

During the first eight or ten practices on the number-alphabet test the subjects are engaged in the relatively complex task of forming associations between twenty-six numbers and letters, and the capacity to deal with this ideational problem determines their achievement. As these associations became practically mastered by the subjects there was a gradual transition from difficulty in finding or recalling the correct response to difficulty in writing as rapidly as the correct responses could be recalled. This transition was clearly indicated by the remarks of the subjects between the eighth and twelfth practices. This was discovered more objectively in a subsequent experiment by the present writer in which one group practiced this test with written responses for ten days while another group practiced it subvocally. At the end of ten days written responses were required of those who had practiced subvocally, and subvocal responses were required of those who had been writing. The results showed clearly that the lack of ability to write as rapidly as the associates could be recalled was a definite handicap.

We may say, then, that before the tenth practice is reached, this test begins to depend more and more upon speed of writing and less upon ability to carry on associative learning. Further evidence of this characteristic of the test is shown by the increasing of the correlation between achievement and mechanical speed during the latter half of the experiment. Attention must be called again to the possibility that conclusions based on a partial mastering of a learning test may be erroneous.

In view of the fact that the data obtained from these experiments consisted of scores made on several trials each (practice) day, the writer has attempted to discover whether convergence or divergence, as the case may be, takes place *during* practice or *between practice periods*. This was studied in two ways. First, the variability coefficient for each trial within every practice was calculated and the first trial was compared with the last trial for the effects of practice, and the last trial of one day was compared with first trial of the succeeding day for the discovery of the effects of the interval between practice. Table IV gives the data from which this study was made in connection with card sorting. Note that if only the first ten practices had been considered we should have reliable evidence that the subjects became more alike while practising and more unlike during the intervals. When the whole process is considered, however, such a conclusion cannot be drawn. The actual differences between convergence and divergence are not great enough to be statistically reliable.

Secondly, the mean achievement scores for each practice have been correlated with (1) the amounts of convergence during practice, (2) the amounts of divergence during practice, (3) the amounts of convergence between practices, and (4) the amounts of divergence between practices. This is simply another statistical device for getting at the same problem. The only reliable coefficient obtained was $.51 \pm .10$ when the means are correlated with divergence between practice, which may be taken as a fair indication that subjects become more unlike during the rest-periods in card sorting.

TABLE IV

VARIABILITY COEFFICIENTS FOR THE THREE TRIALS OF EACH DAY'S PRACTICE IN CARD SORTING, WITH THE CONVERGENCE AND DIVERGENCE DURING AND BETWEEN PRACTICES INDICATED

Practices	Variability coefficients for Trial 1	Trial 2	Trial 3	During Practice Converg.	Diverg.	Between Practices Converg.	Diverg.
1	.170	.124	.190		.020		
2	.249	.279	.235	.014			.059
3	.237	.267	.236	.001			.002
4	.301	.232	.237	.064			.065
5	.249	.254	.196	.053			.012
6	.214	.225	.185	.029			.018
7	.208	.198	.180	.028			.023
8	.178	.200	.173	.005		.002	
9	.200	.153	.128	.072			.027
10	.204	.208	.141	.063			.076
11	.143	.160	.156		.013		.002
12	.155	.149	.145	.010		.001	
13	.161	.190	.169		.008		.016
14	.179	.160	.161	.018			.010
15	.137	.138	.163		.026	.024	
16	.155	.183	.173		.018	.008	
17	.154	.170	.172		.018	.019	
18	.175	.182	.217		.042		.003
19	.161	.176	.200		.039	.056	
20	.187	.168	.183	.004		.013	
21	.179	.140	.122	.057		.004	
22	.152	.152	.158		.006		.030
23	.145	.153	.155		.010	.013	
24	.141	.113	.106	.035		.014	
25	.158	.146	.125	.033			.052
Means*	.184	.181	.172	.020	.008	.006	.016

Net mean convergence during practice, .020 − .008 = .012
Net mean divergence during practice, .016 − .006 = .010

* The last four means in this line are obtained by dividing the sums by the number of cases possible (twenty-five during practice, twenty-four between practices) rather than by the actual number of coefficients in each column.

The results from the other two experiments, obtained from similar analyses of the data, do not support this single barely reliable coefficient. The contribution of this part of the study is the method by which this problem can be investigated in experiments planned mainly for discovering the comparative effects of practice and rest-periods on group-variability. The present investigation seems to indicate that there are some consistent trends which may possibly be brought to light and found reliable in data obtained from more extensive experimentation. In the card-sorting test used

here, the practice periods averaged less than 30 minutes, whereas the interval between practice was $47\frac{1}{2}$ hours.

Interpretation and Discussion

According to the results of this investigation, intelligence seems to be a descriptive term referring to the general ability to react consistently to complex situations. Those using the term aim to generalize about the type of behavior which the organism manifests in a diversity of experience, especially in those situations for which the organism has no ready response, innate or acquired. Responses cannot, of course, be classified into two groups, the intelligent and the non-intelligent; on the contrary, we think of behavior as varying in degrees from the most to the least intelligent. The extent to which responses may be called intelligent may vary with continued practice in one task, as shown by the data obtained in the present study. Intelligence seems to be involved more in the preliminary adjustment to relatively simple situations, less in subsequent achievement, and least in the mechanical limits of ability. That is to say, selecting the significant element out of a situation involves intelligence, whereas mastering these intelligently selected elements requires learning ability. Roback [11] has pointed out that seeing a problem may denote a higher degree of intelligence than solving one.

Learning ability, on the other hand, refers to one's ability to react to more restricted and specialized situations in such a way that a well-integrated adaptive response of a mechanical type is rapidly perfected under continued practice. As the term is used at present, learning ability refers both to rate of learning and to limits of ability. The relationship between these two factors is a problem for investigation. The present study is concerned mainly with limits of learning.

In order to distinguish now between intelligence and learning ability, we may take the case of a subject continuing practice on an intelligence test. In so far as the subject's responses become restricted and specialized, resulting in improvement (i.e. greater rapidity and a nearer approach to his

[11] A. A. Roback, Intelligence and behavior, *Psychol. Rev.*, *1922*, 29, *54–62*.

limit of ability), just so far do those responses become less intelligent and take on more of the nature of learning activity. If, with continued practice on a test, subjects make no improvement, their responses may not be characterized as learning. Theoretically considered this behavior would be purely intelligent, but practically no such behavior is found. In the same way, even a simple learning test, such as card sorting, is, in reality, more of the nature of an intelligence test when first presented to subjects; but as soon as the subjects commence to achieve, learning begins and the behavior may be said to become less intelligent. We do not need to hold, however, that when the activity becomes relatively automatic the process reaches a stage that is wholly learning and not at all intelligent. The extent to which such behavior approaches a zero degree of intelligence depends upon the simplicity of the task and the amount of practice. An infinite amount of practice in an activity of absolute simplicity would be required before a point would be reached at which we could say the behavior was non-intelligent. Briefly put, the more complex a response the more novel the situation in which it is made, and the more it involves selection from a repertory of variable responses the more aptly such a response may be described as intelligent; whereas, the more simple, narrow, mechanical and invariable a response becomes with continued practice, the better it may be described as learning.

This view of learning is in accord with the evidence for specificity in learning abilities found in the investigations of Haught, Sisk, Bernstein, Dowd, Steacy [12] and others. They have shown that no high correlations exist between abilities, speeds or achievement in different tasks. There are types of learning corresponding to the different kinds of problems which an individual faces. Therefore the expression 'learning

[12] B. F. Haught, The interrelation of some higher learning processes, *Psychol. Monog., 1921, 30, (no. 139)*; T. K. Sisk, Interrelations of speed in simple and complex responses, *George Peabody Contrib. to Educ., 1926, (no. 23)*; E. Bernstein, Quickness and intelligence, an enquiry concerning the existence of a general speed factor, *Brit. J. Psychol. Monog. Suppl., Cambridge, 1924;* C. E. Dowd, A study of the consistency of rate of work, *Arch. of Psychol., 1926, 13, (no. 84);* F. W. Steacy, The interrelation of mental abilities, *Teachers Coll. Contrib. to Educ., 1919, (no. 95)*.

ability' is less accurate than 'learning abilities,' unless one refers to a specific task. The results of this investigation indicate that intelligence is measured better by highly complex and varied materials, and that limits of learning are better measured by tests which are comparatively simple and closely related to the activity in which the learning is to take place. Mechanical speeds, according to our definition and to the actual data obtained, are not closely related to intelligence. But they are closely related to the achievement that results from practice, and the relationship becomes closer as practice continues. This leads to the view that mechanical speeds are the real bases of limits of learning in tasks where speed of response is the goal. The importance of something we may call 'mechanical accuracies,' if such a thing exists, is merely one of a number of complicating factors yet to be investigated.

The application of the results of this study may be made in the field of education or industry. Rational analysis of an activity for the purpose of finding the mechanical aptitude underlying it is the first step. From this point experimentation is the method to follow. A verification of these results can best be attempted by way of application to practical problems. Link [13] has found that rate of tapping correlated only $.135 \pm .07$ with performance in shell inspecting, where keen eyesight is the first essential. A simple mechanical-speed measure, involving speed (and accuracy) of visual perception, would give a better basis for predicting proficiency in this work, if the results of the present study are valid. Link also reports that rate of tapping correlated $.516 \pm .07$ with 'gauging,' an activity in which speed of movement is very important. An even better measure of capacity for achievement in this occupation might be found in some simple process which involves the handling of the same materials in a simpler situation and which depends upon a combination of innate and acquired responses already integrated to such an extent that little or no improvement may result from practice. Intelligence tests, at one extreme, and simple reaction time

[13] H. C. Link, An experiment in employment psychology, *Psychol. Rev.*, 1918, 25, 116–127.

measures, at the other, have proved to be of little value in revealing capacity to achieve. The concept of mechanical speed suggests an unexplored region in which the worker in applied science may search for something useful.

Conclusions

1. Intelligence and learning ability, as measured by the tests used in this study, are not identical.

2. An intelligence test is likely to excel a test for mechanical speed in predicting how well a subject enters upon a new task.

3. Intelligence tests do not, in processes similar to those used in this study, predict limits of ability as well as do tests of mechanical speed provided the latter are well chosen.

4. Quickly and easily secured measurements of mechanical speeds in the particular tasks to be learned are fairly reliable instruments for predicting intermediate achievement and limits of ability in those tasks.

5. Subjects tend to become more alike under continued practice in card-sorting and substitution tests. They may become more unlike for a time in less simple tests, such as the number-alphabet substitution; but, if practice is continued, they may then tend to become more alike again. On this matter more materials are needed.

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OCULAR DOMINANCE DEMONSTRATED BY UNCONSCIOUS SIGHTING

BY WALTER MILES

Psychology Laboratories, Stanford University

I

Single vision is to double vision almost as daylight is to darkness! The individual suffering from diplopia may in fact welcome the darkness because it gives relief from the confusion and struggle between the disparate visual fields. Single vision is so naturally the aim and functional objective for man that we can hardly believe our eyes on reading von Graefe's (1) description of cases exhibiting what he calls "antipathy to single vision." It is about as surprising as it would be to find a man habitually exhibiting the exact opposite of conjugate eye movements.

There is what may be called normal diplopia which every individual having two good eyes must learn to live with. This is due to the fact that most objects in any given field of view do not cast their images on corresponding points of the two retinæ. For each fixation point, or distance of fixation, there is an "horopteric surface," which includes all objects that are seen single, while others, if examined closely, will be found double. This physiological diplopia is in the daily practice of normal-eyed individuals combatted by two complementary methods; (*a*) disregarding double images and (*b*) giving one eye the dominance. In ordinary visual experience, attention is, as we know, seldom given to double images resulting from objects nearer or farther away than the fixation point. As noted by Maddox (2) the indistinctness of objects by reason of their casting double images is usually not analyzed as different from the indistinctness caused by an object's being out of focus. Ocular dominance tends to clear the visual field by giving the right of way to the image that belongs to the dominant eye, making it appear more substantial than the other which then tends to be more or less suppressed.

In projecting a lantern slide or film a point-source of illumination is required for securing sharp definition. Similarly when "projecting the retinal field into space," to quote Maddox (2), "the mind must have some point of origin for the radius vector, or line of direction, in which the projection is made." This point may be assumed with Hering as midway between the eyes, and called the "cyclopic eye," or we might regard one eye as the "directing eye" (Javal) and consider that the origin of projection coincides with the position of this eye while its mate serves rather as *aide-de-camp* functioning regularly in a supporting capacity especially when depth perceptions are required.

Very early medical writings mention strabismus (Stevens, 3) and so recognize the fact of binocular vision as a phenomenon of normal vision, but it is apparently very little discussed. As for one eye being used more than the other I can find no hint of this in the first available discussions of vision. Neither Aristotle nor Theophrastus mentions such a tendency, nor does Pliny in his haphazard but extensive and interesting collection of items about the eyes (4). Probably Leonardo da Vinci, writing a little earlier than 1500, was not the first specifically to analyze the difference between monocular and binocular vision, but it is doubtful if anyone before him had done it more thoroughly (5). His lettered diagrams and explanations in connection with discussions of perspective, relief and related topics leave nothing to be desired. But he always seems to assume the two eyes as equal. Durand and Gould (6) quote some interesting passages from Porta, *De refractione*, 1593, which, since the original is so difficult of access, may be requoted. "Nature has bestowed on us eyes in pairs, one at the right hand and one at the left, so that if we are to see anything at the right hand we make use of the right eye . . . whence we always see with one eye, although we think that both are open and that we see with both." "Between the two eyes let there be placed a partition to divide the one from the other, and let us place a book before the right eye and read. If anyone shows another book to the left eye it will not only not be able to read, but it cannot even see the pages, unless in a moment it withdraws the visual virtue from the right eye and changes it to the left." "If anyone places a staff before him and brings it directly opposite some crack that exists in the opposite wall, and notes the place, when he closes his left eye he will not see the staff removed from the opposite crack, the reason being that every one looks with his right eye as he uses his right hand."

Scattering references to ocular dominance may be found in more recent writings. Donders (7) has a section on differences in the refraction of the two eyes and states that constant exclusion of one eye may result. He says, "it certainly is true, that we usually abstract from the one eye more easily than from the other. If anyone causes the sight to be directed to a remote object, it appears, on subsequent closing of the left eye, almost always, that the right eye has been used. If a distant object be covered with the extended finger, this covering will by most people be effected for the right eye. Now where there is difference in refraction that eye is used, with which, at the required distance, vision is most acute and easiest" (p. 559). Helmholtz has apparently no

mention of the matter.[1] Hall and Hartwell (8) in their very comprehensive discussion of "bilateral asymmetry of function" (1884) give brief mention to the phenomenon of pointing in the line of the right eye in right-handed persons. Rosenbach(9) practically repeats (1903) the statement of Donders quoted above. He says, "Upon the request to place binocularly the finger in the sagittal plane it is brought without exception in front of the right eye." He thus contributes nothing new by way of technique or data. In the same year Thompson (Woolley) (10), in a study of the mental traits of sex noted that there were more men than women with weak left eyes but she did not further discuss ocular dominance. A first-rate although brief contribution to the subject appeared in 1910 (Enslin, 11), being a report on 65 left-handed adults examined by the sighting-past-the-finger method, which the investigator had found recommended by Rosenbach. There were 58 of the 65 patients who had equally good vision in both eyes; but only 20 of these brought the finger in front of the left eye. This failure of more than half of the left-handed to demonstrate left eye sighting Enslin checked by repeated testing of his cases and he declares it as especially remarkable, because he had found *all* right-handed to sight with the right eye. Enslin's are the earliest quantitative results that I have found on the problem and he is also the first to raise the interesting question of comparing right- and left-handed people with reference to their ocular habit.

II

Superiority of one eye in comparison with the other may show in so many ways that it is very natural that different methods should have been proposed for ascertaining which eye is dominant.

In 1925, Mills (12) published on eyedness and handedness, reporting results on approximately 1000 cases taken as they came in ophthalmological practice. He used a *convergence test.* In this the patient is asked to fixate the central aperture in a plane mirror held about two feet away and in the median line. Then the mirror is moved slowly toward the subject until the near point of convergence is reached and passed, when the subordinate eye "tends to diverge more or less sharply." The test is said to be definite and striking when there is exophoria; whereas, in cases of esophoria it may have to be repeated or it may be necessary to hold the mirror a few seconds at the maximal near point to tire the adductor muscles. Mills gives his gross results in terms of handedness and eyedness combined. Of those examined 76 per cent were found to be both right-handed and right-eyed; 13 per cent were right-handed but left-eyed; 9.3 per cent were left-handed and left-eyed; and 1.7 per cent were left-handed but right-eyed. Therefore a total of 78 per cent gave right eye and 22 per cent left eye dominance. Mills' convergence method is objective, it may be repeated. The patient is asked no questions, and need not know what is being determined. As a test, maximal convergence (examining only near vision) requires exceptionally good coöperation and is apt to be tiring. For the latter reasons it cannot well be applied to small children. Three years later Mills (13) gave a second discussion of the results of the convergence test and of the application of ocular dominance to other ophthalmological questions. A discussion by medical colleagues is included with Mill's paper.

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[1] Dr. Southall, editor of Helmholtz, *Physiological optics,* Eng. trans., 1925, gives a footnote (Vol. III, p. 7) stating that nearly everyone has a dominant eye but that not many persons are aware of the fact.

Another method of testing for dominance has been suggested by Pascal (14), who calls it the *chromatic test*. With both eyes open the subject looks at a white light. Then a red glass (the usual red disc from the trial case) is placed alternately over each eye and the patient is asked to tell which eye gives the more red and about how much more. Before the test is given the eyes are corrected to equal acuity. During the test the red is changed rapidly to give good opportunity for comparison and if diplopia is present the glass is held several inches in front of the subject. Pascal reports 92 per cent right-eyed, 6 per cent left and 2 per cent neutral. The chromatic test is highly subjective: the patient must be informed of the fact that a difference between the eyes is sought, and it appears doubtful whether the judgments of children can be trusted in this case.

Many variations of the *sighting test* exist and it is in this type of behavior that a method of revealing ocular dominance is usually sought. In the widely-used form, sometimes called the Rosenbach test, but which should perhaps really be credited to Porta, the patient is asked to hold a pencil at arm's length and to line it up with a mark on the wall. With all its faults and poorly controlled conditions this test commonly shows which eye the patient prefers to use. We note that ordinarily the examiner, right-handed, will stand on the patient's right side and give him the pencil with which the test is made. This will then be carried by the patient's right-hand and moved into position from the right side of the visual field, of course coming in line with the right eye first. The whole procedure is strongly prejudiced by the matter of handedness. As a test it could be improved by having the subject first clasp both hands in his lap, then take the pencil between his thumbs and lifting it from below in this position place it in the proper line. If the test were carried out in this way a natural choice would probably be more nearly made. Durand and Gould (6) improved the sighting test by using a cardboard 12 x 6 inches with a hole in its center and a piece of tube pushed through the hole. When held at arm's length one eye or the other had to be used in looking through at a small target on the wall beyond. Their instrument had a handle somewhat like a stereoscope, a feature that seems to the writer a very decided disadvantage in any eye-dominance test. Gould (15) had discussed dominance quite fully in his book on handedness which was brought out in 1908, but so far as found he has given no experimental results on ocular dominance.

After making trials with pointing, pencil aligning and having the subject approach objects and align himself with them, Dolman (16) settled on a test which resembles that of Durand and Gould. He used a card 13 x 20 cm with a 3-cm round hole in the center. Grasping one end of the card with each hand the subject raised it slowly at arm's length while looking intently at a spot of light six meters distant. He was instructed to keep both eyes open and to find the light through the hole. Of course the situation forced the use of one eye or the other. Dolman makes the point that the influence of the right or left hand on the test was much lessened by his method and states that the results were consistent with repeated trials on the same people. Up to 1919 this was the best controlled test procedure for dominance that had been used. Five years later Parson (17) published his description of the manuscope (or manoptoscope) and so stimulated much interest in the entire problem. His device and testing method has been recently described in this Journal (see Cuff, 18). By adopting the hollow truncated cone held with the base covering the face Parson forced unilateral sighting while the subject has the impression that he sees the target with both eyes. This is an important advance in dominance testing for the subject tested need not know that he is really sighting with a preferred eye. Curiously enough Parson largely sacrifices the advantages of the viewing cone by the testing procedure which he has proposed:

the subject is asked what he sees, rather than watched to determine how he sees it, and he is permitted to hold the manuscope in one hand, thus prejudicing the results in favor of that side.

III

The A-B-C Vision Test, Miles (19), is a direct outgrowth of Parson's suggestions and Dolman's practice. It proceeds on the obvious basis that unilateral sighting is behavior that the examiner can observe without need of asking the subject what he is doing, and that if the subject is sufficiently interested in the visual targets presented he will go ahead with his sighting behavior without realizing that he is actually using one eye predominantly.

Special sets of test-cards are used. One card from the adult series is illustrated in Fig. 1. Each card in this series

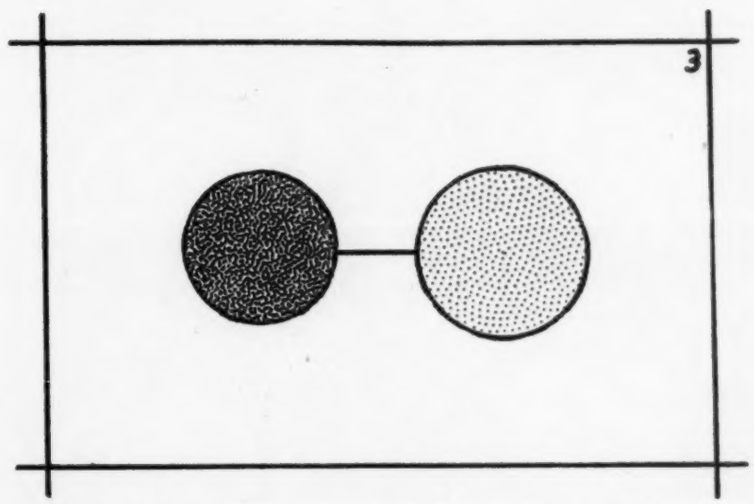

FIG. 1. A sample test-card to be used with the V-Scope for determining ocular dominance. The attention of the subject is controlled by giving a short exposure of the card and requiring him, after looking at it through the V-Scope, to tell which spot is larger and which is darker. The examiner himself looks past the card and notes which eye the subject, who is ten feet from the card, uses.

has printed on it two round spots that differ in size and shade. The subject is told that a card will be shown for only a short period and that he must decide which spot is larger and which is darker. The test-cards are viewed through a paper funnel or V-Scope that is made of folded white cardboard formed in such a manner that it *must be pressed open between the two hands* if the subject is to see through the aperture. The form of the V-Scope, its use, and the means by which the experi-

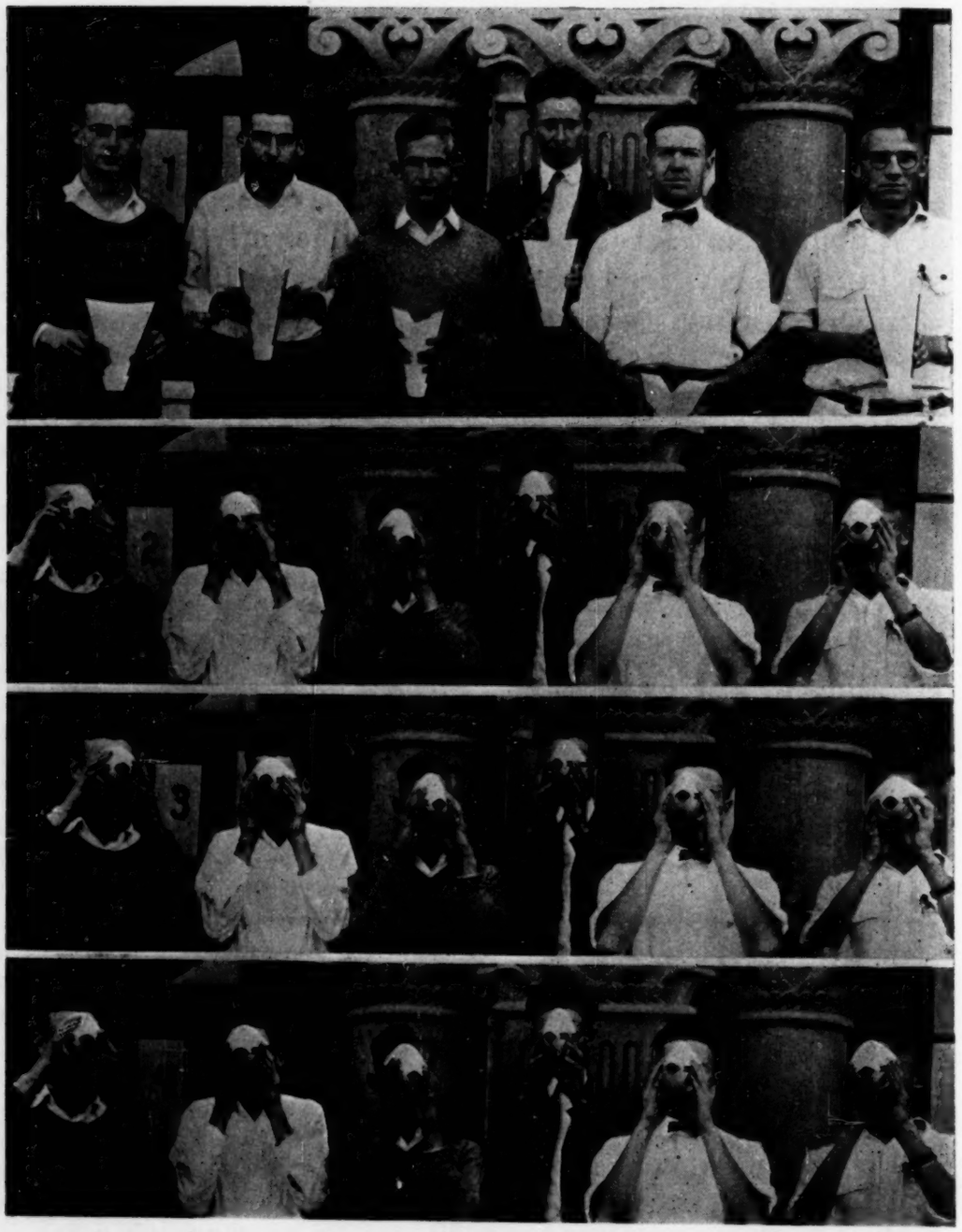

PLATE 1. A series of photographs showing directly the ocular dominance of the men tested. In photograph 1 the men are ready for the test but naive as to what it is about. In 2, 3 and 4 three separate trials are illustrated. Each man is consistent in all three trials. The subjects do not realize that they are using only one eye.

menter can tell which eye the subject is sighting with will be clear from Plate 1. Of the six men shown, only the one at the extreme right knew anything about the test. He had served as a subject in an experiment. An exterior focal-plane shutter was used on the camera with which these views were taken. The men were told to watch the shutter very carefully and to note if they could see when the opening occurred. The men were not allowed to explore by looking through the V-Scopes before or between the tests. Between trials the funnels were held as in the top view. The three test pictures, 2, 3 and 4, were taken at intervals of about one minute. It will be noted that the three views show perfect consistency for each man; counting from the left, Nos. 1 and 3 each use the left eye, Nos. 2, 4, 5 and 6 use the right eye. It is a curious fact, but absolutely typical for the V-Scope test, that after the three tests no one of the six men could tell that he had not been using both eyes in watching the camera shutter. It is easily possible to repeat the test many times and on different occasions without the subject becoming aware of the fact that he is sighting with one eye.

Standard directions for giving the test should be used. They are as follows;

1. Do not tell the person to be examined that this is a dominance test. You want him to respond naturally, therefore keep him in ignorance of your real purpose. Call it "A-B-C Vision Test" which means Area-Blackness-Comparison. Say: "*Keep both eyes open. I am going to test your sharpness and quickness in seeing.*" Do the test rapidly (1 or 2 minutes).

2. The subject may stand or be seated. The examiner is 10 feet away and facing him. Say: "*I will expose a card for a moment while you look at it through the V-Scope. You will tell me which of the two spots on the card is larger and which is darker. The two spots will always differ from each other in size and darkness. Press the V-Scope open with both hands and when I count 'one, two, up' bring it up and look through it at the card.*" (If you show him how to use the V-Scope, turn to the side, do not look at him, or he may get the trick and see that only one of your eyes shows.)

3. Now hold one of the test-cards edgewise in front of your face and just below your eye. Say "*one, two, up*" and at exactly the moment when he looks at you through the V-Scope, turn the face of the card so he can see it for about 2 seconds, while you say "*one, two, down.*" Immediately he lowers the V-Scope and tells you what he saw. You examine the card to note if he is correct. But the real purpose of the test is *your seeing directly* which eye he uses at the moment when he looks at the card. *Note this closely; be sure you are correct.* Verify your result by trying several cards. A series of 10 is suggested, as the first trial is often not typical. Always have the subject change

V-Scopes at each trial. This gives a new motor adjustment. Do not let him explore about, looking through the V-Scope before or between tests, as this may spoil later trials with him.

4. With small children and adults for whom the two-spot cards may be too difficult, use the picture cards. Use a short exposure and then say "*What was it?*" Adapt the instructions to the comprehension of the individual. Have his attention well centered on the cards and he will unknowingly demonstrate his 'dominance' habit. The V-Scope can also be used for showing the dominance at reading distance.[2]

IV

A group of somewhat more than 500 individuals ranging in age from 3 years upward to adulthood has been tested at Stanford with the A-B-C Vision Test as described. I have found that the test can easily be given to children who are 5 or 6 years old and in individual instances to pre-school children. Plate 2 shows Photographs 3 and 4 of a series of viewing trials like those of Plate I described above. The subjects are normal, unselected first-grade pupils in a Palo Alto public school. All of the pupils in a single class were used. They were instructed as a group, not individually, and it was apparent to the investigator, and is also evidenced by the pictures, that practically all got the idea and coöperated satisfactorily. There is only one clear instance of inconsistency. The fifth child in the middle row uses his right eye in Photograph 3 and his left in 4. The second child in the bottom row does not cover the face with the V-Scope and has closed his left eye as if in aiming. It must be understood that the test as such is not recommended for group application. The pictures were taken and are reproduced that the reader may gain a clearer impression of the objectivity of the examination and the uniformity with which it operates. The group-method could perhaps be used in a preliminary way, *e.g.* to segregate for some further study those who indicated left-eye preference or irregularity of performance.

Typical results for 172 pupils, the entire attendance of the first five grades in a public school, are presented in Table I.[3] The pupils were all tested individually by the same examiner

[2] The testing outfit consisting of three V-Scopes, two sets of special cards and printed directions may be secured from the authors.

[3] The capable assistance of Mrs. Ruth Wilson in giving the test to these children is acknowledged.

PLATE 2. Normal first grade children (5 and 6 years) unconsciously exhibiting their ocular dominance in a group test

and were given 10 trials under favorable conditions. The picture test-cards were used.

TABLE I

SAMPLE RESULTS ON OCULAR DOMINANCE IN GRADE-SCHOOL PUPILS

Grade	1	2	3	4	5	Totals	Per cent
No. of pupils	33	29	21	41	48	172	100
Pupils, 10 right eye	20	20	10	26	28	104	61
Pupils, 10 left eye	7	8	6	5	11	37	22
Pupils, 7+ right eye	3	0	1	1	6	11	6
Pupils, 7+ left eye	1	1	3	7	2	14	8
Pupils, indefinite	2	0	1	2	1	6	3

The results are given under five heads for each of the five school grades. First is the number of pupils who always, *i.e.* in all 10 trials, showed only the right eye; these comprise 61 per cent of the entire group. Secondly, 22 per cent who always showed the left eye. Third and fourth, a certain number of pupils who seem to demonstrate dominance but will occasionally show the subordinate eye. These cases where 9, 8, or 7 of the trials have been either left or right have been grouped separately, and there are 6 per cent of one and 8 per cent of the other. Where a subject gave 6 of one and 4 of the other, it was considered that no dominance was indicated by the test. Such cases are included under the last heading.

If we accept the statement of the teacher and of the children concerned, there were 7 left-handed pupils in the group. Two gave 10 left and four gave 10 right; there was one who gave 9 left and 1 right. Of the right-handed 100 gave 10 right and 35 gave 10 left. There were a few mixed or indefinite cases.

The reliability of the test was determined by a retest one week after the first which included re-examination of 59 of the pupils; 19 from the first, 7 from the third and 33 from the fifth grade. Of these, 44 individuals (75 per cent) gave full agreement between the two series of results and all 10 of the same eye both times. There were 11 (19 per cent) cases classed as substantial agreement which means 7 or more for the same eye in each test. One, a first-grade child, agreed with himself in indicating no dominance on either occasion. Two showed partial lack of agreement, and a third-grade girl

gave first 10 left and later 10 right, *i.e.* complete reversal. The two examinations thus gave results which checked substantially in 56 out of 59 cases, 95 per cent agreement. This indicates a high degree of reliability for the test as applied.

Results secured from adults are briefly shown in Table II.

TABLE II

THE RELATIVE PROPORTION OF RIGHT- AND LEFT-EYE DOMINANCE SHOWN BY ADULTS TESTED WITH THE V-SCOPE

	Subjects	Right Eye %	Left Eye %	Indefinite %
Psychology majors	45	67	33	0
High School	50	64	18	0
Chinese men	20	65	35	0
Medical students [1]	37	76	24	0
University women	26 [2]	58	35	7
University men	25 [3]	64	24	12
Total	203			

[1] Microscope users, most of whom were trained to use the left eye.

[2] All tested a second time; 21 gave identical results.

[3] All retested; 20 showed perfect agreement.

The results for the pupils in the lower grades, 67 per cent right and 30 per cent left eye dominance, agree well with the values we have obtained for adults.

Parson (17), using his manuscope, reports on 877 public school children in Elizabeth, New Jersey; 69 per cent right eye, 29 per cent left and less than 2 per cent indefinite. Apparently these results were from making just one trial on each pupil. The average age was about 10 years. Cuff (18), using the manuscope and giving five trials in succession at one sitting with each child, examined a school of 146 pupils containing groups from the third to the tenth grades inclusive. His total results show 62 per cent right-eyed, 29 per cent left-eyed and 9 per cent "impartial-eyed." From the combined results it seems quite certain that a normal population will show a proportion of about 65, 30 and 5 per cents. Kuroda (20), whose work I know only at secondhand, is said to report Fujioka as finding only 35.3 per cent of children examined having a monocular habit, and he says that Ozaki found 31.3 per cent. Kuroda states that right- and left-eyedness "has no significant correlation with homolateral visual acuity and

hand grip, and with right- or left-handedness" (Yoshioka, 20). I do not know what method was used by the Japanese investigators and so for the time being the conflict in results cannot be resolved.

The general result found by Enslin in 1910 seems substantiated; that is, the clearly left-handed are about evenly divided between left- and right-eye dominance, whereas in the right-handed the great majority are right-eyed. Such has been the outcome at Stanford, where we have examined about 50 left-handed, including both men and women, boys and girls. Acquired habits, as for example in the use of the microscope, do not seem to carry over in the test of ocular dominance. The whole question of a dominant cerebral hemisphere as recently discussed in the important paper of Orton (21) is one of very far-reaching significance in human development and efficiency. Ocular dominance by tending to do away with the normal diplopia clarifies the visual field in respect to the exact positions of objects as related to the observer. Hence it is a part of the problem of hemispherical dominance that is now fairly open for study. A form of examination that can be carried out on little children as well as on adults and which brings about, without knowledge on their part, the desired sighting behavior, a test which can be repeated as often as desirable without destroying the naivété of the subjects, should be of aid in this complex field. The test cannot be kept entirely free from the influence of an habitual position of the head and the use of the arms and hands. Together with the eyes all of these systems function unitedly with reference to the objects of space. We have tried in the present test so to arrange that the hands will not have a predominating influence on the results, and this source of error has apparently been largely overcome.

In our experiments we have found a number of individuals who unerringly and unhesitatingly adjust the V-Scope to the dominant eye although they are quite unconscious of the fact that they are using one eye only. Other subjects, also unaware of the 'dominance' phenomenon, show uncertainty in adjustment, have to explore about to find the object, and in

extreme cases are inconsistent in successive trials. What constitutes these fundamental differences in behavior we can at present only conjecture.

Summary

1. While many facts concerning vision were noticed by ancient writers, the topic is discussed by them as if man were a cyclopean creature. Ocular dominance has not been found mentioned earlier than in the writings of Porta, 1593 A.D.

2. Several methods may be used for demonstrating dominance; but the most effective are those that make use of sighting.

3. Unconscious sighting with Parson's manuscope or with the V-Scope here described, when properly conducted, may serve as a test for ocular dominance.

4. On looking through a truncated paper cone (V-Scope), with the base held near the face, a person has the impression that he is seeing a given distant object with both eyes whereas he is really engaged in unilateral sighting.

5. The testing should be done in such a way that the subjects will remain naive as to its purpose and the results.

6. By using a folded cone that must be pressed open between the hands the results are freed in the main from prejudice by the handedness of those tested.

7. High reliability of the test is shown in that 95 per cent of the subjects on whom retests were made gave concordant results.

8. Various groups of subjects, both children and adults, show that for a normal population about 65 per cent will demonstrate dominance of the right eye, 30 per cent dominance of the left, and 5 per cent give mixed or indeterminate results.

9. The left-handed have been found, in agreement with results published by Enslin in 1910, to be about equally divided between right- and left-eye dominance; while the large majority of right-handed are also right-eyed.

10. Ocular dominance is assuming a place of increasing importance in ophthalmology and physiological optics. It is a

phenomenon which may be objectively measured and used in studying the general problem of dominance by the right or left cortical hemisphere.

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CERTAIN FACTORS UNDERLYING THE ACQUISITION OF MOTOR SKILL BY PRE-SCHOOL CHILDREN

BY FLORENCE L. GOODENOUGH AND CLARA R. BRIAN

Institute of Child Welfare, University of Minnesota [1]

Despite the large amount of experimental work which has been carried out in the field of motor learning, few studies have been reported in which the subjects have been children of pre-school age. This lack is the more surprising in view of the theoretical significance of the genetic approach to the study of human behavior. Children's experience is relatively meagre. Hence it is much easier to find situations with which few associations have already been formed and to observe the setting up of a reaction pattern from a form much nearer its origin. The factors influencing the child's behavior are more likely to appear during the actual period of observation, whereas factors influencing adult behavior frequently reside in a series of obscure past events of which the investigator can have no knowledge.

The study about to be described was therefore undertaken with the hope of adding to our information regarding certain fundamental aspects of the learning process, through an analysis of some of the specific factors apparently involved in the acquisition of a novel motor skill by young children. The data have been analyzed both from the standpoint of the results obtained for the group as a whole and for the individual children composing the group. Since changes in the forms of the individual learning curves can properly be understood only in the light of certain results from the entire group, the latter will be presented first and the discussion of the individual learning curves will be taken up in the final section.

[1] Acknowledgment is due to Dorothea McCarthy, Violet Bemmels and Margaret Light, research assistants in the Institute, who conducted the experiments with Groups B and C.

Description of the Experiment

Apparatus and Method. The data of this experiment were obtained from twenty four-year-old children enrolled in the nursery school at the University of Minnesota, Institute of Child Welfare. The apparatus consisted of a ring-toss game with a cylindrical post ¾-inch in diameter, 6 inches high, mounted on a heavy oak platform measuring 12 by 15 inches and 1 inch thick.

The rings were made of ¾-inch manilla rope, and were 7 inches in diameter, measured from center to center of the rope on the two sides. They were joined with adhesive tape. The experiment was carried out in a room 10 ft 5 in by 8 ft 5 in. The children were required to stand with both feet within the area of a rectangular 'base' 15 by 20 inches which was marked out in chalk at one end of the room, and were told to try to throw the rings over the post, which was placed near the center of the room at

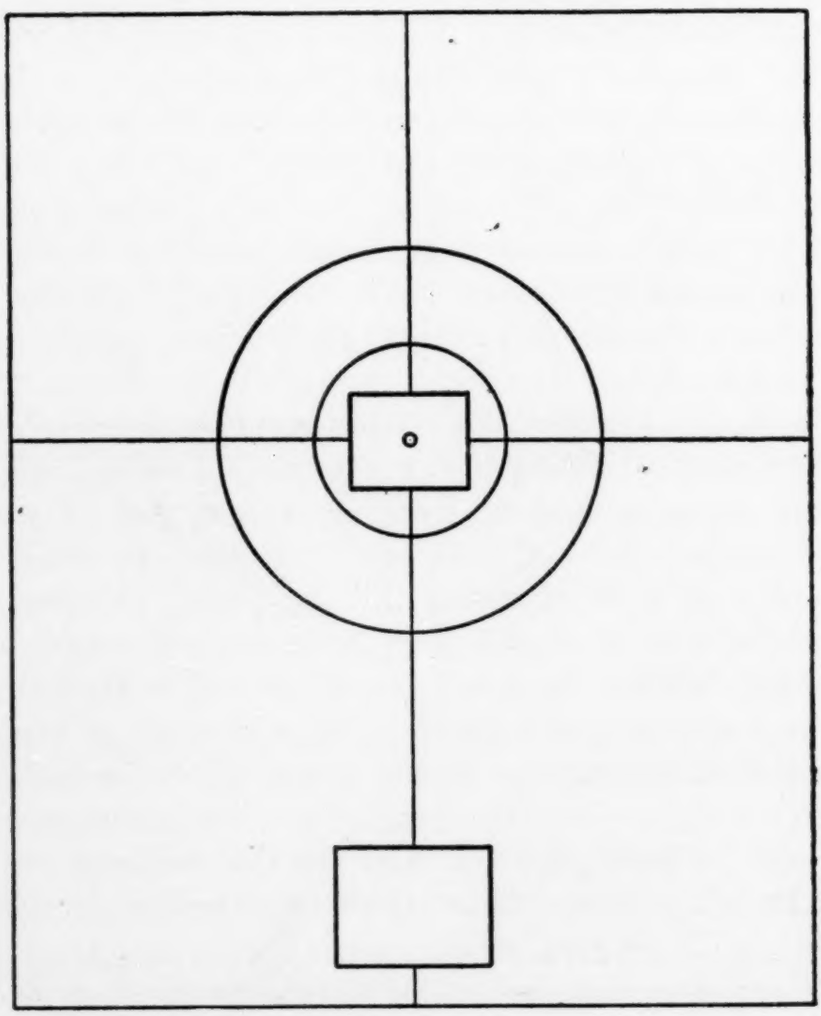

Fig. 1. Floor Plan

a distance of 4 ft 10½ in from the center of the base. Each child was allowed twenty trials a day for fifty days, taken as nearly in succession as week-ends and other absences permitted.

Records of each day's performance were made as follows. Two concentric circles with radii of 12 and 24 inches respectively were drawn on the floor, using the post as a center. In addition, two cross-lines running at right angles to each other and parallel to the walls of the room were drawn in such a way as to divide the entire floor area into four quadrants (Fig. 1). The daily records of each child's performance were recorded by writing the serial number of each throw in a space on a mimeographed duplicate of the floor plan corresponding to the point on the floor upon which the ring fell when thrown. Thus, if the first ring thrown struck in the near right-hand quadrant between the two circles, the number 1 was written in the corresponding space on the record blank. In a similar way the number 2 was used to indicate the position of the second throw, and so on for the entire series of 20 throws. It thus became possible, not only to ascertain the total daily scores for each child, but also to determine the sequence of errors and successes; a point which, as will be shown later, is of considerable importance.

With most of the children, motivation did not constitute a serious problem. They enjoyed the game for its own sake, and were greatly delighted when they succeeded in making a 'ringer.' An additional source of motivation was, however, provided by means of wall charts on which they were allowed to paste stickers, one sticker for each successful throw made. Gold stars, Christmas seals, turkey seals for Thanksgiving, hearts for Valentine's Day, and the like were used. The children were always curious to know what kind of seal would be used on that particular day, and they greatly enjoyed attaching them to their charts. Each child had his own chart, which he was allowed to take home when filled.

The twenty children were divided into three groups. Group A included ten children (four boys and six girls) who were given no instruction whatever as to the manner of throwing. On the first day the children of this group were taken into the room one at a time and were given the following directions. "This is a game where we try to throw rings over a post. You stand here on this base—be sure both of your feet are inside the base all the time—and I'll hand you the rings. Try to throw them on that post over there. Do you see what I mean? All right, go ahead."

The experimenter stood always at the child's right and handed him the rings as they were thrown. Praise and encouragement were given freely, but no criticisms or suggestions.

Group B consisted of six children, two boys and four girls. The procedure for this group was as follows. On the first day the children were taken to the room singly as was done with those in Group A. The experimenter then said, "This is a game where we try to throw rings over a post. Watch me

and I'll show you how." After throwing one or two rings the experimenter continued, "You see how to do it, don't you? You must stand with both feet inside the base—like this—and hold the rings here where they are fastened together, and then try to throw them so they will go over the post. Now you try it."

As the rings were thrown the experimenter pointed out the nature of the errors which the child was making and urged him to correct them.—"Not quite so far next time." "A little bit higher so it won't hit the post," etc. The children were also reminded to hold the rings at the point of juncture so as to insure better balance. Since the rings had been joined with tape, this point was easily found.

Apart from the method of holding the rings and general criticism with regard to distance, direction, etc., designed to prevent the setting up of constant errors, no further instructions were given. The children were permitted to throw either overhand or underhand as they wished. Some raised the rings over their heads and threw downward. One or two squatted upon their heels and threw from that position. Others pitched the rings in quite a professional manner. Each child was allowed to work out his own method as he wished, and most of them changed their procedure one or more times in the course of the experiment.

Group C consisted of four children, two boys and two girls. The procedure used for this group was similar to that used for Group B except that the instruction was more rigid. All the children were required to adhere to a constant method of holding and throwing the rings, and were not allowed to experiment with other methods. They were told to grasp the ring at the point of juncture, hold it in a horizontal position, and after swinging the arm back and forth a few times to pitch the ring forward and upward toward the post. The procedure was frequently illustrated and any departure from the established method was promptly corrected.

The number and distribution of trials were the same for all three groups. All the subjects were approximately four-and-a-half years old at the beginning of the experiment. The

distribution of intelligence test scores was approximately equal for the three groups. None of the children had had previous experience with games of this sort.[2]

Scoring. In the outset it was thought that it would be possible to work out a graded series of scores by weighting each throw according to its distance from the post. The plan was not successful, however, and after a number of weighting schemes had been tried, the weighting method was discarded in favor of a simple all-or-none scoring system in which the number of times the ring was thrown over the post during the twenty trials was used as the score, and all errors, regardless of their nature, were given zero weight.

This method was found to have higher reliability than any of the weighted scoring systems which were tried. The trouble with the latter appears to lie in the fact that the significance of any given error must be interpreted in the light of a number of facts and not simply in terms of the distance between the ring and the post. For example, all the children had more or less difficulty in gauging the proper height for the throw. Many times the ring was thrown too low, so that it struck the post instead of going over it. For several of the children this type of error seemed to be the most difficult to correct, and, particularly in the case of those children who were given instruction, their attempts to overcome the error often resulted in a temporary period during which the rings were thrown wide of the mark. Actual improvement in skill through the breaking up of undesirable habits was often masked by the temporary appearance of compensating errors, which, by a weighted scoring system, appeared to be more serious than the original habit. Other types of performance which were difficult to include in a weighted scoring system but which were important factors in determining success or failure were the angle at which the ring was held in throwing and the force with which it was thrown. Several of the children were inclined to hold the ring in a vertical position so that it struck upon its edge rather than horizontally. The ring might then strike very close to the post but was practically certain not to go over it. One of the children in the uninstructed group developed a habit of raising the rings above her head and throwing with such force that on several occasions a ring which had gone over the post bounced off again immediately. Others showed the same tendency in a less marked degree. It is very difficult to devise an objective scoring system which takes account of all these varying factors, and without such a system partial credits can obviously have but little meaning.

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[2] The writers are indebted to Miss Catherine Thompson of the Institute Staff, who visited all the homes and questioned the parents as to whether the child owned or had ever played with any game of this kind. One child had spent a day in a friend's home where a 'horseshoe' game was in progress, and had joined in the play for some time. This had occurred, however, nearly a year previous to our experiment. All other reports were negative.

General Results

Learning curves.[3] Fig. 2 shows the curves for the individual children in Group A. It is evident from these curves that two of the children in this group (Subjs. 1A and 5A) made

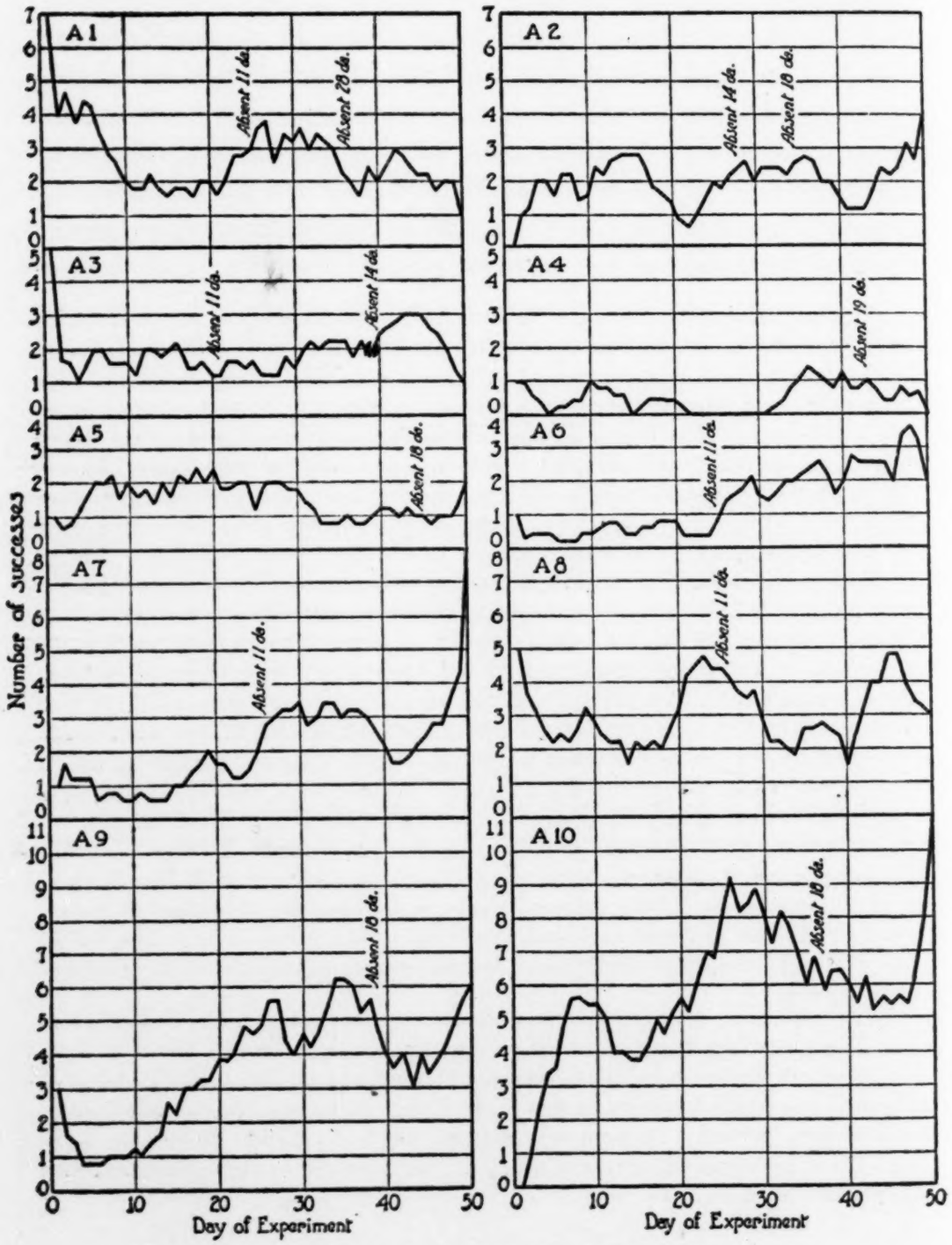

Fig. 2. Learning curves for individual children in group A

[3] All curves have been subjected to a 5-pt. smoothing.

a progressively poorer showing as the experiment proceeded, and that four others (2A, 3A, 4A and 8A) showed only a small amount of improvement. The remaining four (6A, 7A, 9A and 10A) showed a fairly consistent gain throughout the course of the experiment.

The curves for the six children in Group B are shown in Fig. 3. Of these, Subjs. 1B and 2B showed a small amount of gain as the experiment progressed; 3B showed a rapid initial gain with steady deterioration thereafter; 6B showed improvement only during the first 28 days, while 4B and 5B continued to improve throughout the period of practice.

Fig. 4 shows the curves for the four children in Group C. All the children in this group showed improvement throughout the period of practice.

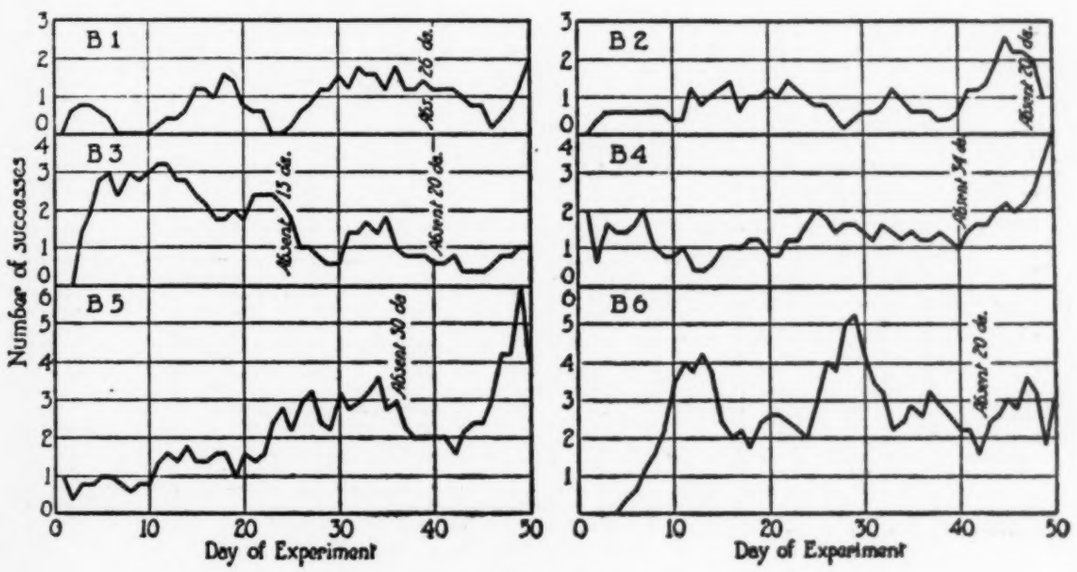

FIG. 3. Learning curves for individual children in group B

If the number of successes made by each individual child on the last 25 days is compared with that earned on the first 25 days, it is found that for Group A the percentages of improvement range from a loss of 34 per cent to a gain of 287 per cent with a median improvement for the group of 36 per cent. For Group B the range is from a loss of 61 per cent to a gain of 147 per cent with a median improvement of 66 per cent. For Group C the range is from a gain of 53 per cent to one of 175 per cent with a median of 92 per cent. The median per-

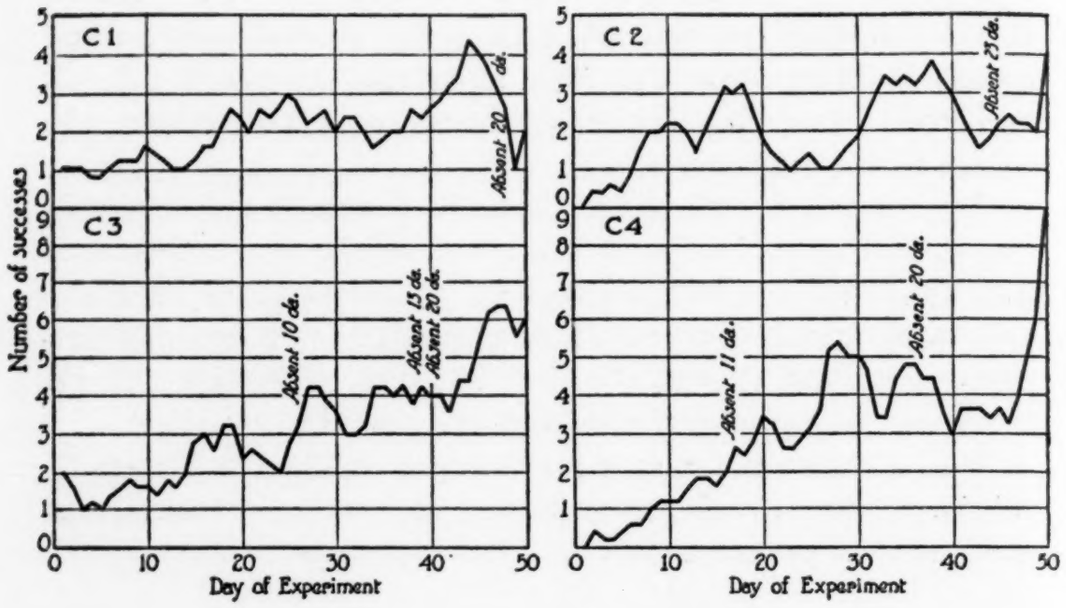

FIG 4. Learning curves for individual children in group C

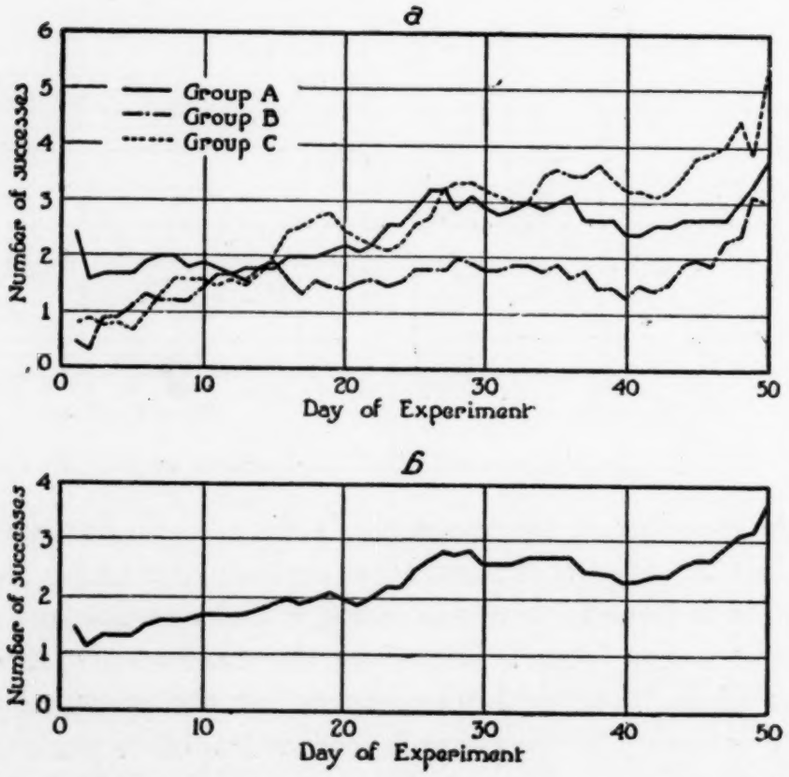

FIG. 5. a. Combined curves for A, B, and C taken separately. b. Combined curve for total group

centage of improvement for the entire group of 20 children is 55 per cent when the scores earned during the first 25 days are compared with those earned during the last 25 days (see Table I). The combined curves for the three groups separately and for the entire group of twenty children are shown in Fig. 5.

TABLE I

AMOUNT OF GAIN MADE BY INDIVIDUAL SUBJECTS

(Last 25 days compared to first 25 days)

	Score		*Gain*	
	First 25 days	Second 25 days	Absolute	Per cent
Group A:				
Subj. 1.....	70	62	− 8	−11
2.....	44	56	12	27
3.....	41	52	11	27
4.....	10	15	5	50
5.....	44	29	−15	−34
6.....	15	58	43	287
7.....	27	75	48	178
8.....	74	78	4	5
9.....	60	116	56	93
10.....	117	170	53	45
Median gain			11.5	36
Group B:				
Subj. 1.....	14	29	15	107
2.....	21	26	5	24
3.....	57	22	−35	−61
4.....	27	47	20	74
5.....	32	79	47	147
6.....	49	77	28	57
Median gain			17.5	66
Group C:				
Subj. 1.....	39	65	26	67
2.....	40	61	21	53
3.....	51	110	59	116
4.....	40	110	70	175
Median gain			42.5	92
Median gain for all groups			20.5	55

Although it is true that the mean initial performance for the children of Group A is somewhat higher than that for either Group B or Group C, this fact does not account for the difference in the percentage of improvement in the three groups, since the gross gains show a similar distribution. The mean gain in score on the second half as compared to the first is 11.5 points for Group A, 17.5 points for Group B, and

42.5 points for Group C. It should be noted further that none of the group curves suggests that the limit of improvability had been reached at the time the experiment was concluded. While the number of cases in each group is too small to warrant a final conclusion, the data suggest (a) that, at least in the case of young children whose powers of self-criticism are but little developed, uncontrolled practice in a performance of this sort is a relatively uncertain means of acquiring skill, (b) that verbal suggestion and criticism alone are of small effectiveness in bringing about improvement, and (c) that continued practice according to a constant method, provided the method be reasonably well suited to its purpose, is more likely to result in improvement in a motor function within a limited period of time than random experimentation with various methods. Further evidence as to these points will be given in a later section.

All the curves show a considerable amount of fluctuation in the child's performance from day to day. Since, as will be shown later on, the reliability coefficient for a single day's practice is not high, fluctuations which have a relatively brief duration can best be attributed to chance factors. A number of the curves, however, show changes which are too marked and too persistent to be accounted for on this basis. These cases will be discussed in some detail in the analysis of the individual curves.

Reliability. Reliability has been computed in several ways.

First, the reliability of a single day's performance has been computed by finding the correlation between the number of successes on the odd versus the even trials on each successive day and correcting by means of the Spearman-Brown formula. By this method, the coefficients obtained were as follows; for Group A, .568, for Group B, .593, for Group C, .618. For the entire group of 20 cases the coefficient was .585. Correlations were also computed between the number of successes on each odd-numbered day with the number on the ensuing even-numbered day. It is to be expected that this method would yield somewhat lower results than the foregoing, both because of minor differences in the child's interest and motivation on different days, and because of true changes in his level of performance from day to day. By this method the coefficients obtained were .535 for Group A, .375 for Group B, .485 for Group C., and .463 for the cases combined. Reliabilities were also computed for successive blocks of ten days each by correlating the sum of the scores earned on the five even-numbered days against the corresponding sum for the odd-numbered days and correcting by the

Spearman-Brown formula. The record for each quintile was entered only once, i.e.the first entry would be the sum of the scores earned by a subject on trials 1, 3, 5, 7, and 9 against the corresponding sum for trials 2, 4, 6, 8, and 10; the second entry would be the sum of the scores earned on trials 11, 13, 15, 17, and 19 against those earned on trials 12, 14, 16, 18, and 20, etc. This method yielded the following results; for Group A, .849, for Group B, .828, for Group C, .936, and for the three groups combined, .900. It would appear, therefore, that while but little dependence can be placed in the day to day fluctuations in an individual learning curve, a change in the direction of the curve which persists over a period of as much as ten days may be considered to have real significance.

Two other methods of computing reliability have been used. The first is similar to that reported in a recent article by Stone and Nyswander[4] in a study of maze learning in rats. This method uses the correlation between the sum of all the scores earned on the odd-numbered days by each of the subjects separately and the corresponding values for the even-numbered days. Because of the very small number of cases when the three groups are considered separately, these figures obviously have but little significance. Rank-order correlations[5] have been computed, however, with the following results; for Group A., $r = .947$, for Group B, .937, for Group C, .974, and for the three groups combined, .933. It should be noted that the above method is applicable only to problems involving a comparison of the total performance of the individual subjects during the entire learning period, and not to the position of any individual at any given period of learning. Its use is permissible only when the entire period of practice is regarded as analogous to a single test-situation. Its magnitude is a function of the differences in ability actually existing between the individual subjects, the amount of the experimental error, and the length of the practice period. If the latter be sufficiently prolonged, even though the reliability of the scores on the individual practice periods be very low, it is possible to increase the reliability coefficient obtained in this way, using a heterogeneous group of subjects, to a point closely approximating unity. In the present experiment, the reliability coefficients reported in the preceding paragraph may properly be said to apply to the correlations between the total scores of the individual children and such other variables as IQ or mental age. For the data having to do with the separate points on the learning curves the reliability coefficients given in the early part of this section should be used.

In order to determine the relationship between initial and final ability it becomes necessary to find the respective reliability coefficients for the beginning and end of the learning curves. Since it was previously found that a ten-day segment constitutes a reasonably adequate basis for determining individual status, reliability coefficients were computed separately for the first ten and the last ten days of practice, using the method just described. For the first ten days the rank-order coefficients were as follows; for Group A, .864; for Group B, .478, and for Group C, .868, and for the three groups combined, .750. For the last ten days of practice the corresponding figure for Group A is .764, for Group B, .939, for Group C, 1.00, and for the three groups combined, .869. The somewhat lower reliability of the first segment of the learning curve is in accordance with the usual reports of other investigators.

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[4] C. P. Stone & D. Nyswander, The reliability of rat learning scores from the multiple T-maze as determined by four different methods, *Ped. Sem.*, 1927, 34, 497–524.

[5] All correlations have been computed by the Pearson product-moment method unless otherwise stated.

Correlation between initial status and gain. The correlations between the total scores earned on the first ten days of practice and the gain when this measure is subtracted from the total score earned on the last ten days was computed for the three groups separately and for the total. The results, when corrected for regression by the method derived by G. H. Thomson,[6] were as follows; for Group A, −.197, for Group B, −.487, for Group C, +.029, and for the three groups combined, −.055. While the number of cases is too small to make these figures more than suggestive, it is interesting to note that they are in general agreement with the results of other investigators in the field of motor learning who have usually reported a zero or negative correlation between initial scores and gain after practice.

Correlations with intelligence quotients. Each of the subjects had been given from three to seven intelligence tests, including the Kuhlmann-Binet, the Minnesota pre-school tests, the Merrill-Palmer performance scale, and the Stanford-Binet. A weighted mean of the results was taken, giving double weight to the tests given during the current year, single weight to those given during earlier years, and disregarding all tests in which the child's coöperation was in any way open to question. Rank-order correlations were then computed between these results and the total number of successful throws made during the fifty-days' practice. The results were as follows; for Group A, −.548, for Group B, −.067, for Group C, +.028, and for the three groups combined −.349. The small negative correlation is probably of no significance. Rank-order correlations were also computed between the intelligence test results and the gain as represented by the difference between the scores earned on the first and last ten days of practice. Again the correlations tend toward the negative direction, though to a lesser degree than when the absolute values are used. These results do not suggest that scores on the ordinary types of intelligence test have any marked bearing upon the child's performance in a task of this kind.

[6] G. H. Thomson, A formula to correct for the effect of errors of measurement on the correlation of initial values with gains, this JOURNAL, 1924, 7, 321–24.

Sex differences. While the number of cases is too small to warrant generalization, it is interesting to note that in each of the three groups, the boys exceed the girls in mean total score on the fifty days' practice. The means for the sexes are as follows; for Group A, boys 168, girls 89; for Group B, boys 95, girls 72; for Group C, boys 133, girls 130. For the three groups combined, the mean score for the boys is 141, for the girls, 91. Only 25 per cent of the girls equal or exceed the median score of the boys; only 50 per cent do as well as the poorest boy. The girls, however, show a slightly greater improvement with practice, but the difference is small. The mean gains, when the sums of the scores on the last ten days of practice are compared with the corresponding figures for the first ten days, are for Group A, boys, 7, girls 13; for Group B, boys 7, girls 12; for Group C, boys 29, girls 22; and for the three groups combined, boys 12, girls 14. While the girls have improved their relative positions to a slight degree, they are still considerably behind the boys at the end of the fifty-days' practice.

Distribution of successes by order of trial. In order to ascertain to what extent, if at all, improvement takes place during the course of the individual practice periods, the successful throws made during the fifty-days' practice were tabulated according to their serial numbers. The results are shown in Table II.

TABLE II

DISTRIBUTION OF SUCCESSES BY ORDER OF TRIAL

	Trials 1–5	Trials 6–10	Trials 11–15	Trials 16–20
Group A	286	308	309	313
Group B	119	126	113	129
Group C	116	108	149	150
Total	521	542	571	592

When the total group of twenty subjects is considered, it is seen that a fairly regular improvement takes place from the beginning to the end of each day's practice. The last five trials of the practice period are 13.6 per cent more likely to be successful than are the first five.

Distribution of practice periods. The daily practice periods

were of necessity interrupted by week-ends and other holidays, and by occasional absences of children from school. It was thought worth while to tabulate successes with reference to the distribution of the practice periods in order to see whether any reliable difference might appear. The results, which are shown in Table III, are, however, inconclusive. The first part of the table suggests that absences of from one to five

TABLE III

DISTRIBUTION OF PRACTICE; MEAN NUMBER OF SUCCESSFUL THROWS MADE AFTER VARYING PERIODS OF PRACTICE OR LACK OF PRACTICE

I. *After a given number of successive days' absence*

Days absent	0	1	2	3	4	5	6 or more
Group A:							
No. cases	308	50	82	26	10	5	19
Mean	2.88	1.74	2.30	2.42	3.20	2.20	3.16
S.D.	2.32	1.63	2.08	1.68	3.07	1.51	2.86
Group B:							
No. cases	207	21	41	11	10	0	10
Mean	1.59	2.14	1.41	1.28	1.80	—	2.30
S.D.	1.98	1.64	1.27	0.94	1.64	—	1.76
Group C:							
No. cases	128	17	29	13	2	2	7
Mean	2.53	2.80	2.80	2.54	2.00	1.50	3.57
S.D.	1.48	1.84	1.86	1.72	1.50	1.50	2.10
All cases:							
No cases	643	88	152	50	22	7	36
Mean	2.40	2.04	2.16	2.20	2.45	2.00	3.00
S.D.	1.64	1.71	1.82	1.60	1.98	1.50	2.15

II. *After a given number of successive days' practice*

Days present	0	1	2	3	4	5	6 or more
Group A:							
No. cases	192	120	89	61	38		
Mean	2.34	2.47	2.39	2.59	2.32		
S.D.	2.11	2.14	1.86	2.28	1.94		
Group B:							
No. cases	93	78	57	46	26		
Mean	1.62	1.52	1.55	1.50	2.15		
S.D.	1.73	1.28	1.50	1.30	2.03		
Group C:							
No. cases	70	46	35	30	19		
Mean	2.67	2.43	2.25	2.67	3.11		
S.D.	2.13	1.78	1.42	1.51	1.64		
All cases:							
No. cases	355	244	181	137	83		
Mean	2.22	2.16	2.10	2.24	2.45		
S.D.	1.96	1.84	1.68	1.84	1.92		

days in duration may result in a slight falling off in efficiency; though the standard deviations are high and the differences are within the limits of chance variation. The apparent improvement following absences of six or more days is in part spurious; a result of the fact that a large proportion of these absences occurred near the end of the period of practice. Analysis of the individual curves, however, suggests that long absences are frequently followed by a decided change in the form of the learning curve, and that this change may take the form either of improvement or retrogression, according to circumstances. The position of each absence of ten days or longer has been indicated on the individual curves. Examination of these curves will show that in many instances these absences coincide with the appearance of a distinct modification in the form of the learning curve. This point will be brought out more clearly in the following section, which deals with the individual curves.

The second part of Table III, in which the data are treated with reference to the number of successive days' practice, shows practically no difference in the mean number of successes made after zero-to-three consecutive days' practice, and a small but unreliable improvement after four consecutive days' practice. The results may be taken to mean either that, within the limits of variation which occurred during this experiment, regularity of practice is a factor of rather minor importance in the acquisition of a motor skill by young children, or, more probably, that the irregular distribution of the periods of absence over the total learning period has tended to obscure whatever differences were present.

The grouping of successes within the learning period. One of the most fundamental problems in the entire field of the psychology of learning has to do with the question of how errors are eliminated, or conversely, how successes are built up. The exceptional simplicity of the task under consideration, involving, as it does, the mere repetition of the same act for a specified number of times, makes it possible to attack this problem from an aspect which differs somewhat from the methods employed by previous investigators.

It is obvious that simple repetition of an act cannot in itself result in an improved performance unless the repetition be accompanied by an increase in the proportionate number of correct acts with a corresponding decrease in the proportionate number of incorrect acts. Since it has repeatedly been urged that associations are formed more readily between acts or events which are near together in point of time than between those which are chronologically remote from each other, it seems reasonable to suppose that improvement in a performance of this kind may be in part dependent upon the ability of the individual to maintain a kind of kinæsthetic orientation or 'set' which will enable him to reproduce with comparative exactitude those actions which have proved to be successful. The hypothesis is therefore put forth that one of the important factors in the acquisition of motor skill is the ability to take and maintain a kinæsthetic orientation or set, and that the extent to which this factor is exhibited will be manifested by the extent to which successful performances are grouped together in excess of the proportion expected by chance.

It remains to check this hypothesis in the light of the available data.

When both the number of trials and the number of successes are known, the chances that these successes will be grouped in each of the various possible ways can readily be computed. The possible number of such groupings increases very rapidly, however, as the number of successes increases. With 8 successes out of 20 trials there are 22 possible ways in which these successes may group themselves even if serial order be disregarded; e.g. if 3 successes occurring in succession, with the remaining successes distributed singly, be regarded as the same, no matter at what point in the series the three successive correct throws occur. The amount of data necessary if all possible combinations are to be treated separately is very great. In view of the rather limited material furnished by our 20 subjects it seemed advisable, therefore, to treat the data from the negative aspect only; reserving the more conclusive positive treatment[7] for a larger study which is now in progress.

[7] The positive treatment is more conclusive only in the sense that it makes it possible to weight the results according to the likelihood of any given combination occurring by chance. It utilizes all the data and not merely a limited part. For example, if there are four successes in twenty trials, the possible groupings with their chance expectancies are as follows; no two occurring in succession, 49.1 per cent of the cases; two in succession and two singly, 42.1 per cent; three in succession and one singly, 5.6 per cent; all four in succession, 0.4 per cent of the cases; and two groups of two each, 2.8 per cent. It is apparent that any of the last three groupings, because of

We have therefore disregarded, or rather, treated as equal, all cases in which at least two of the successful throws occurred in immediate sequence, and have considered only the proportion of cases at each level of success in which no two consecutive trials were successful. If the proportion of non-consecutive successes is smaller than that to be expected by chance, it follows of necessity that the number of consecutive successes must be greater than would occur by chance.

The data were at first summarized for the three groups (A, B, and C) separately. As no reliable differences between the groups were apparent, the cases were then divided upon the basis of the learning curves. The ten subjects whose curves showed the greatest amount of improvement during the learning period (Subjs. 6A, 7A, 9A, 10A, 5B, 6B, 1C, 2C, 3C, 4C) were compared with the ten whose curves showed least improvement and also with the chance expectancy. The results are shown in Table IV, and in Fig. 6.

TABLE IV

COMPARISON OF ACTUAL GROUPING OF SUCCESSES FOR GOOD AND POOR LEARNERS WITH CHANCE EXPECTANCY (EXPRESSED IN TERMS OF PERMILLES OF ACTUAL AND THEORETICAL TOTALS)

Non-consecutive successes (in permilles)	2	Number of successful throws in twenty trials 3	4	5	6	7	8*
Good learners	872	707	508	212	77	0	0
Poor learners	889	723	452	236	200	0	0
Chance expectancy	900	716	491	282	155	44	12

* There were no non-consecutive successes on the days with more than 8 successfu throws. Because of the small number of cases, these have not been included in the table.

It is seen that the good learners show a tendency toward grouping of successes which is in excess of the chance expectancy in six out of the seven determinations, and in excess of that shown by the poorer learners in four instances, while in two instances the proportions are the same for the two groups of subjects. The poorer learners show a grouping which is in

their relatively infrequent occurrence, should be given much more weight than the second, that of a single pair, which occurs by chance in 42 per cent of the cases. An attempt was made to include these infrequent occurrences by weighting inversely as the chance expectancy and combining. With the relatively small amount of material at hand, the fluctuations of sampling were found to be so great that the attempt was discontinued. One of the writers is now securing comparable material upon a much larger group of subjects. It is hoped that when this study is completed, the matter can be put to a more rigid test.

excess of chance in five of seven determinations, in excess of the better learners in one instance, and equally as good as the better learners in two instances. While the differences are small, they are fairly consistent and lend some support, at least, to the hypothesis previously suggested. It should be noted further that the extent of departure from the chance expectancy increases rather markedly for the group of better learners with increase in skill as measured by the number of successes; a fact which is also in accordance with the hypothesis put forth.

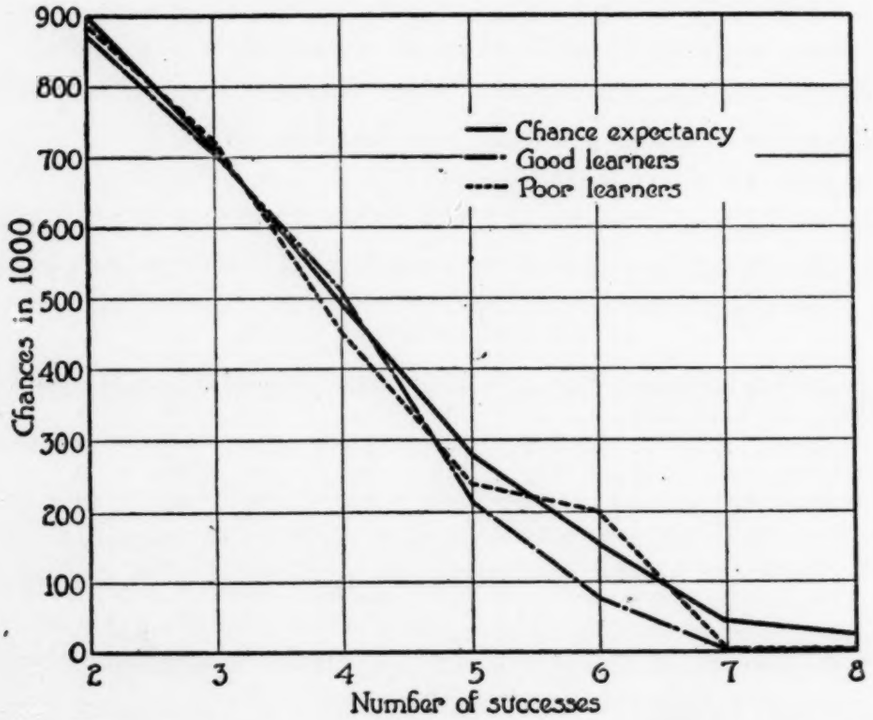

FIG. 6. Comparison of successful groupings for good and poor learners with chance expectancy

The effect of success upon the type of performance. When the nature of the errors was examined, it was found that the greater number of the children showed some tendency to throw beyond the mark. This tendency, however, was not distributed at random, but was far more evident in the errors immediately following successful throws than in those following unsuccessful throws. This rather curious point calls to mind Münsterberg's observations on the expansive outward-

going movements accompanying the pleasurable emotions. The extent of the tendency may be judged from the following summary. Of the 20 subjects, 17 show this characteristic to some extent, while in the remaining 3 cases the differences are negligible. For the entire group of 20 cases, the difference between the proportion of overthrown errors following successes as compared to those not following successes is 5.47 times the standard error of the difference, and would occur by chance only once in several thousand times.

The tendency seems to be equally marked whether the child in general tends toward overthrowing or underthrowing. Subj. 1B, for example, throws beyond the mark in 64.0 per cent of the errors not following successes, and in 79.1 per cent of those following successes, a difference of 15.1 per cent; while Subj. 4A, who overthrows in only 35.3 per cent of the errors not occurring after successes, increases this ratio to 50 per cent on the errors following successes.

In order to see whether the individual differences with regard to this tendency appeared to be related to the usual degree of emotional response shown by the subjects, three of the nursery-school teachers were asked to rank the children according to the intensity, quickness and variability of their usual emotional responses. The mean ranks thus obtained were then correlated by the Spearman rank-order method against the differences between the individual percentages of overthrowing before and after success. The correlation obtained was .325, which, in view of the small number of cases, is of rather doubtful significance. It was noteworthy, however, that the low correlation was due almost entirely to three cases of very marked discrepancy between the teachers' ratings and the overthrow data. Two of these were very shy, quiet, repressed children who took little active part in the nursery-school activities and were rated by all the teachers as showing very little emotional responsiveness. Both showed very marked differences in their overthrow records. The third is an active, flighty child who constituted the only serious problem of motivation found in the group. His learning curve (3B) shows a rapid initial rise with steady retrogression thereafter, which is almost certainly due to loss of interest. He was ranked very high in emotional responsiveness by the teachers but is only average in his overthrow record.

Errors in direction of throw. All of the children showed a preferential use of the right hand, though several occasionally changed to the left, and one or two, as will be noted in the following section, used both hands. Owing to the mechanical structure of the body, there is a general tendency for the arm to swing in a somewhat inward direction when brought forward as in throwing, with the result that, unless this tendency is especially guarded against, a greater number of the errors will be expected to fall to the left than to the right of the goal when throwing is done with the right hand. This was found to be

true for the average of each of the three groups and to about an equal extent.

The individual children varied considerably with regard to this characteristic, the ratio of left to right errors ranging from 0.75 for Subj. 3B to 2.17 for Subj. 2A. The differences, however, appear to be uncorrelated with individual differences in learning. This is equally true whether learning is measured in terms of total number of correct throws, in gross amount of gain on the second half of the experimental period as compared to the first, or in the ratio of the number of successes on the second half as compared to the first; and whether the error scores are ranked in order from the greatest percentage of left errors to greatest percentage of right errors, or, as seems more logical, in order of the extent to which the percentages depart from an even 50–50 ratio. The significance of these differences remains undetermined.

Analysis of the Individual Records

It now becomes possible to consider the learning curves of the individual children with a view to ascertaining, where possible, those factors which have been influential in determining the changes in the level of performance which occur from time to time. Rather full notations were made on each child's daily records as to his apparent interest and effort, any changes in his method of holding or throwing the rings or in his general bodily posture, etc. Verbatim records were also made of any comments which the child made on his own performance or other significant remarks. In analyzing the records these notations have been considered as well as the data on the location of the separate throws.

Subj. 1A made seven correct throws on his first day of practice, which is a greater number then was made at the start by any other child in the group. Although his mother was quite certain that P— had never played with it, a small ring-toss game had been packed away with some discarded toys in the family attic, hence it is possible that there had been some previous practice in this case. He was extremely proud of his superior performance and boasted about it repeatedly. "I get more ringers than anybody else, don't I?" "Gee! what a lot of stickers I have on my card!" were frequent comments during the first few days. For the first three days his errors were nearly equally divided between overthrows and underthrows. On the fourth day a pronounced tendency toward overthrowing became apparent, with 9 out of 13 errors overthrown. This tendency increased steadily until during the period from the thirteenth to the seventeenth days inclusive, 73 out of 92 errors were overthrown. About this time new charts were given out, P—'s array of stickers no longer presented so imposing an appearance, and his self-confidence began to wane. "I hope I'll get a lot today" and "Maybe I can get better tomorrow" are characteristic remarks of this period. Overthrowing became much less frequent, dropping to 47 per cent of the total number of errors made between the 20th and 24th days. On the 18th day he had discovered for himself that the rings balanced better if held at the point of junction.

From that time on he continued to be very punctilious about this point, frequently remarking "I must always take them here, musn't I?" This discovery, together with correction of the tendency to overthrow the mark, apparently accounts for the rise in the curve at this point. The second falling off in performance which began about the 35th day, and, with the exception of a brief period of improvement around the 40th day, continued to the end of the practice period appeared to be the result of a curious association of meaning with the word 'careful,' which to him seemed to be synonymous with 'gentle.' "I must be careful today, mustn't I?" he would say repeatedly. Taking the ring gingerly between finger and thumb he would toss it with the utmost gentleness, with the result that it often fell a considerable distance short of the mark. He appeared to see no connection between his 'carefulness' and the resultant error; and on several occasions remarked after a failure of this sort, "I'll be carefuller this time," and repeated the performance exactly. During the last eight days of the practice period 75 per cent of the errors were underthrown. It is not known how this peculiar verbal association arose, as the expression had not been used by the experimenter at any time.

This case furnishes an interesting example of retrogressive learning through the setting up of incorrect modes of response in spite of excellent effort on the part of the subject. Interest was apparently very keen throughout the experimental period; he was always eager to come to the laboratory to "play the ringer game," was delighted at each successful throw and disappointed at each failure. Indeed, this very interest appears to have reacted unfavorably for success in his case; first through creating over-self-confidence, and later on through the development of undue anxiety and caution.

Subj. 2A. The curve for this subject shows five fairly well-defined periods; an initial period of improvement from the 1st to the 14th day, a period of retrogression from the 15th to the 22d day, a second period of improvement from the 23d to the 35th day, a second period of retrogression from the 36th to the 42d day, and a final period of improvement from the 43d to the 50th day.

Initial interest was very high in this child, who is a somewhat backward and very excitable boy with IQ of 85. He soon discovered that he could do better if he stepped forward toward the post when throwing, and objected rather strenuously to the requirement that he keep on the base. The first drop in the curve seems to have been largely the result of a temporary falling off in effort during a period when the child's attention appeared to be directed more toward watching for an opportunity to steal a few inches' advantage in position than toward improvement in his general technique. These attempts were gradually discontinued, however, and a second period of improvement set in which was interrupted by the development of a marked tendency to overthrow and to swing the arm across the body when throwing so that nearly all the rings were thrown beyond and to the left of the post. During the first five days of the second period of improvement, 60 per cent of the errors were too far to the left. This proportion steadily increased until during the second period of retrogression 82 per cent of the errors were thrown to the left, and nearly all of these in the upper left quadrant. This tendency was overcome to some extent during the last eight days when the proportion of errors thrown to the left dropped to 68 per cent, with an accompanying partial correction of the habit of overthrowing, represented by a change from 84 per cent overthrown during the period from the thirty-sixth to the forty-second day, to 64 per cent during the last eight days. At no time throughout the experimental period did this child make any sort of verbal criticism of his performance other than simple ejaculations of pleasure at a correct throw or of disappointment at failure.

Subj. 3A is a little girl with IQ of 150. Like Subj. 1A she started out at a relatively high level, making five successful throws on the first day. The rings were pitched from

beneath with the right hand. On the 2d and 3d days the rings tended to be thrown too high, so that they sometimes turned over two or three times before reaching the floor. The child noted this, saying, "I throw them up too much, don't I?" On the 4th day, apparently in an attempt to overcome her tendency to "throw them up," she began grasping the rings tightly with both hands, palms down and thumbs underneath, in a singularly awkward manner, frequently accompanying her throws with a peculiar little rabbit-like hop which seemed to be occasioned by difficulty in releasing the ring simultaneously with both hands. Sometimes the hands failed to synchronize so that the ring fell almost at her feet. She continued to use both hands until the 45th day of practice when five of the twenty trials were thrown with the right hand only. From then on to the 50th day her procedure was erratic; she threw sometimes with one hand, sometimes with both; the one-hand throws were made sometimes overhand, sometimes underhand, and the ring was grasped in various ways. She appeared to be experimenting with various methods. It is unfortunate that the school term ended just at that time, as it would have been interesting to see whether she would have developed a favorable method and adhered to it thereafter. Interest and motivation were exceptionally good throughout.

Subj. 4A made a rather promising beginning with very well directed throws all of which were close to the goal. On the 5th day she developed a habit of pitching the rings too low, so that they struck the post instead of going over it. On the 6th day the post was hit in 14 of 20 trials and there were no successes. This was followed by a seven-day period of erratic throwing when many of the rings went wide of the mark. By this time, Subj. 10A had reached a fairly high level of proficiency, and 4A repeatedly commented on his success and requested to be allowed to watch him so that she could learn his method. This was refused, but on the 13th day she slipped up to the laboratory when 10A was taken up for his turn, and as the door of the research room had been left open she was able to watch the performance from the hall without the experimenter's knowledge. When her turn came she was at first radiant with expectation. "I'll get a lot today," she predicted confidently. When the first ring was put into her hands, however, she appeared self-conscious. Holding the ring in one position after another, she asked, hesitatingly, "How did E— do it? Was it like this?" Eventually, after several false starts, she grasped the ring from underneath in an extremely awkward manner, with wrist bent and elbow thrust out in front of her body, and tossed it with a peculiar whirling motion so that it fell just to the right of her feet. She was disappointed, but repeated the performance in a similar manner. This practice continued with occasional slight modifications until about the 35th day, and reappeared intermittently to the end of the practice period. About the 35th day she returned, for the greater part, to her original method of pitching the rings, and some improvement appeared; but she continued to have difficulty with hitting the post. During the last few days the rings were frequently thrown in a vertical position so that they struck on the edges rather than horizontally.

Subj.5A. For the first three or four days this child appeared to be interested chiefly in simply throwing the rings and made little apparent effort to get them over the post. As this interest developed she soon arrived at a point where she was averaging about two successful throws daily. She did not, however, build up any consistent method of holding or throwing the rings but grasped them at any point and threw sometimes overhand, sometimes underhand, sometimes raising the rings high above her head and throwing downward, sometimes squatting on her heels and tossing them upward. She was very distractible and often failed to look at the post when throwing. Apart from the slight initial and final rises, her curve appears to be divided into two

plateaus, the second showing a lower level of efficiency than the first. The loss of efficiency may have been due in part to lowered effort. This was difficult to determine as her conduct was very erratic throughout, though she seemed to enjoy the game and was always ready to come to the laboratory. Nevertheless, an examination of her records shows a somewhat increased tendency to strike the post in throwing after about the 30th day. While there was an occasional day's exception, this tendency gradually increased until, on the 50th day, 14 out of 18 errors struck the post.

Subj. 6A at first threw the rings with a decided twist of the wrist, producing a whirling movement by which the rings often fell almost at her feet. From this she changed to raising the rings high above her head, then throwing them downward with much force but little attention to the angle at which they were held, so that they frequently struck upon the edge. For the first twenty-three days she alternated from one to the other of these methods, during which time her curve shows but little progress. An eleven-day vacation then intervened, and on the first day after her return she spontaneously adopted an overhand pitch which was quite different from either of her former methods. She adhered to this method until the end of the practice period and made steady improvement throughout. Special inquiry was made at the home to ascertain whether or not any instruction or practice had been given during the vacation period. There had been none. It seems, therefore, that the chief importance of the eleven-day interval lay in the fact that it permitted the former undesirable habits to become weakened through disuse, so that a new method was more readily adopted.

Subj. 7A shows only slight and irregular improvement during the first 23 days of practice. During this time she continually experimented with various methods of throwing, frequently changing her procedure four or five times during the course of a single day's practice. She did not hold the rings at any particular point, and many of the throws were made with the ring held in a vertical position so that it struck upon the edge and rolled. On other occasions she raised the ring high over her head and threw it directly downward, so that it struck nearly at her feet. Interest was very keen throughout, and she frequently volunteered critical comments on her own performance, although these criticisms often missed the essential point. For example, on one day when the type of error last described was giving her particular trouble, she remarked, "They don't go high enough," and endeavored to correct the difficulty by raising herself on tip-toe and stretching her arm upward to its utmost limits before dropping the ring.

As with Subj. 6A, marked improvement is first seen after the spring vacation. For the first time she adopted a consistent method of holding and throwing the rings, grasping them always at the point of junction, raising them to the level of her shoulder and throwing downward. There is a brief period of retrogression, however, during the period from the 38th to the 43d day, which, as in the case of Subj. 1A, seemed to be the result of a specific verbal association. "I must try *hard*," she would say. "Trying hard" seemed to be synonymous with throwing hard, and for a time she flung the rings downward with so much force that in two instances the tape fastenings were broken and had to be repaired. If a ring chanced to go over the post it was likely to rebound off again from the force of the impact. Since no stickers were forthcoming under these circumstances, her ardor rapidly diminished, and as her violence decreased, improvement again set in.

Subj. 8A made five successful throws on the first day, using an underhand pitch with the right hand. On the second day, several of the throws were made with both hands, and for several days thereafter both hands were used at least part of the time. On the 7th day he began for the first time to grasp the rings at the point of juncture

most of the time, though he sometimes forgot to do so, and still used both hands for an occasional throw. There was a brief period of improvement at this time, which disappeared as he developed a peculiar twist of the wrist which caused the rings to turn over in the air before striking the floor. This was followed by a period when nearly half of the errors were thrown too low so that the rings struck the post below the top. This tendency disappeared rather suddenly following a four-day absence, and the 21st day marked the beginning of a period of definite improvement, which was again cut short as a habit of over-throwing put in an appearance. From the 21st to the 25th day inclusive, 64 per cent of the errors were overthrown; from the 31st to the 35th day, 89 per cent were overthrown. This drops to 70 per cent during the final period of improvement which begins about the 40th day. Interest was keen throughout.

Subj. 9A, after a brief period of experimentation, developed a constant method of holding and throwing the rings to which she adhered throughout the experimental period. She was careful to grasp the rings at the point of juncture, raised them shoulder high, and threw downward. Steady improvement was shown, except for a single brief drop which coincided with certain unusual activities elsewhere and may have been an expression of slight fatigue. With this exception, improvement continued steadily until after the Christmas vacation, when there is a marked drop in efficiency which is only just beginning to be made up at the end of the experimental period. This record, taken in conjunction with those of Subjs. 6A and 7A, suggests that interruption of practice in the acquisition of a motor habit may function either to the advantage or disadvantage of the learning individual, according as the particular habits which are in process of formation are desirable or undesirable. If the subject is improving his efficiency, a temporary discontinuance of practice may result in a loss of skill previously attained. If, on the other hand, continued practice is operating merely to fix undesirable habits more firmly, a period without practice, which permits the undesirable habits to become weakened through disuse, may be the best possible preparation for the establishment of more desirable habits.

Subj. 10A, whose performance as measured in terms of the total number of successful throws was the best in the entire group of 20 children, had two periods of retrogression which interrupted the general upward slope of his learning curve. He began to hold the rings at the point of junction within the first week of practice, and throughout the experimental period continued to toss the rings with an underhand pitch with very little change in his general procedure. The first falling off in success occurred in conjunction with a brief period when the arm was swung across the body in throwing, with the result that during four consecutive days 80 per cent of the errors were thrown to the left. The second and more protracted period began immediately following the Thanksgiving holidays, and was marked by alternation from days on which the difficulty appeared to be primarily a matter of the cross swing previously described to others on which practically all the errors struck the post below its top. The difficulty became more marked after the Christmas holidays, and definite improvement did not reappear until just before the end of the experimental period.

Subj. 1B is an excitable and high-strung child, whose curve shows alternating periods of success and failure, which appear to be closely related to her emotional reactions. She was greatly fascinated by the game and usually begged to be the first one chosen to play. She was very awkward in throwing, however, and had to be continually reminded to keep her eye on the post. Her first attempts were described as "pushing, rather than throwing. She holds the ring out and drops it, or gives it a sudden jerk which sends it far beyond the post. Is heartbroken when it doesn't go on."

Periods of elation when some degree of success was attained alternated with periods

of discouragement when she announced, sometimes with tears, that she couldn't see "any use in playing the ringer game if you can't get any ringers." That some improvement took place during the fifty days' practice is indicated by the fact that she made 29 successful throws during the last 25 days as compared to 14 during the first 25 days. This improvement appeared to be due to simple gain in muscular control, rather than to any definable improvement in technique. It will be recalled that the instruction given to Group B children took the form of general verbal comment, suggestion and criticism, and did not involve the consistent following of a specified procedure. This child, although she stands high on her intelligence test records with IQ of 130, did not appear to be able to carry over these verbal suggestions into the field of motor behavior.

Subj. 2B shows a similar inability to profit by verbal suggestion. The daily notes bear comments such as these, "Cannot remember to watch the post when throwing. Looks at it when reminded, but eyes are likely to wander again immediately and she seems to throw at random." "Continues to throw the rings too far in spite of reminders." Posture and general procedure were changed frequently, though her most frequent method was to stoop down, holding the ring between her knees with the back of the hand forward, and then to toss the ring forward and upward. She used the right hand for the greater part, but occasional throws were made with the left hand, and both hands were sometimes used during the first few days of practice. There is only a very slight improvement from the beginning to the end of the practice period. During the first half of the period she made a total of 21 correct throws, as compared to 26 during the second half.

Subj. 3B, as has been noted before, was the only child in the group with whom motivation was any serious problem. He was keenly interested for the first few days and showed rapid improvement during this time. He then developed a peculiar twist of the wrist in throwing which caused the rings to turn over in the air and frequently to strike upon the edge. He became much discouraged over the falling off in his success, and although he continued to come to the laboratory without protest, and although occasional brief revivals of his original enthusiasm recurred, usually he merely tossed the rings hastily and carelessly, making very little real effort at success. The pronounced drop in the curve after the rapid initial rise is almost certainly to be attributed to loss of interest.

Subj. 4B. Except for a brief period in the early part of the experimental period when interest seemed to lapse somewhat, motivation was good throughout. There is very little improvement, however, during the first forty days of practice. The difficulty appeared to lie chiefly with her inability to remember to hold the rings in a horizontal position when throwing. Reminding seemed to have but little effect, since even if she poised the ring carefully in a horizontal position as instructed immediately before throwing, she was likely to allow it to drop to a vertical position in the act of throwing. As in the case of Subj. 6A and 7A, improvement was much more rapid after the Christmas holidays.

Subj. 5B, a boy with IQ of 128, is the only child in Group B who appeared to benefit to any extent by the type of instruction given. The daily notes include frequent comments such as the following, "Tried to follow instructions. Much self-criticism." "Asked the experimenter whether he was holding the rings correctly." "Compensates for errors; too long shots likely to be followed by underthrowing. Comments freely on his own performance." Improvement was not rapid, but was fairly steady up to the time of the Christmas vacation, which a severe cold prolonged into a thirty-day absence. There was a distinct drop in his performance at this time, but improvement again appeared and continued to the end of the practice period.

Subj. 6B[8] has an irregular curve, the changes in which are not always easy to account for. There was frequent self-criticism throughout the experimental period, but very little evidence of success in carrying out instructions. Interest was keen throughout. There is a general tendency toward overthrowing, which is, however, especially marked during the two periods of retrogression. This tendency is much less marked after the Christmas vacation, when, as can be seen from the curve, improvement again sets in after a plateau which has lasted for over two weeks.

Subj. 1C showed a steady, slow improvement during the first twenty-five days, followed by a period of slight retrogression during which he was inclined to try to depart from the established procedure and try methods of his own. (It will be recalled that the children in Group C were required to follow a standard method throughout the experimental period.) After several days during which it was necessary to use constant reminders to induce him to adhere to a uniform procedure, he gave up his attempts at experimentation and improvement again appeared and continued until after the Christmas vacation, which, in his case, occurred between the 46th and 47th days of practice. In the brief period of time remaining to him, the efficiency lost at that time was not again regained.

Subj. 2C shows two periods of improvement, each followed by a period of retrogression, and a final brief period of gain at the end of the fifty days' practice. Both drops in the curve appeared to be associated with defective attention. The first was a period of marked general distractibility, which was exhibited particularly in an almost uncontrollable tendency to chatter on all sorts of subjects, with consequent failure to center her attention on the task in hand. This difficulty was gradually overcome by calling her attention to the better records made when she "kept very quiet and tried hard." The second period of improvement was interrupted by the development of a habit of watching the movements of her arm and hand instead of looking at the post. This was begun before the Christmas vacation and continued to some extent afterward. There was a brief period of improvement during the last few days of practice.

Subj. 3C showed a very steady improvement throughout the period of practice. His most serious difficulty was a general tendency toward overthrowing.

Subj. 4C developed a habit of throwing too low, so that the rings struck below the top of the post during the latter part of the experimental period. This habit persisted for several days, and although she herself noticed it and commented on it, she appeared to be unable for some time to correct the trouble. Apart from this, her curve shows steady progress throughout the period of practice.

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[8] An amusing fabrication invented by this child during the experimental period may be noted in passing. On arriving at the laboratory one morning she announced, "My mother's going to buy me a ringer game like this." The next day she was very jubilant, "My mother's gone down town today to get the ringer game. When I get home, it'll be there." The following day she reported its arrival, and almost daily thereafter she recounted not only her own successful performances in this game, but those of all her family and friends. "Yesterday night I made thirteen ringers, 'n Richard made ten. Gee, I can throw 'em good at home." Several of the other children also reported home "ringer games" though none with the persistence and wealth of detail supplied by this child. In each case the reports were checked and found to be purely imaginary. They furnish amusing illustrations of the working out of 'wish fulfillment' in the imaginative falsehoods of young children.

Summary

1. A total of 20 four-and-a-half year old children were trained for 50 days in throwing rings over a post set at a distance of 4 feet, 10½ inches. Twenty trials were allowed each day. Records, showing the number and serial order of the successful throws, and the number, serial order and types of errors, together with descriptive notes as to the method of holding and throwing the rings, comments and criticisms made by the child, and any other apparently significant facts were kept for each day's performance.

2. The 20 subjects were divided into 3 sub-groups; Group A included 10 children who were given no instruction or criticism with regard to their methods of throwing; Group B included 6 children who were given a brief preliminary demonstration and subsequent verbal criticism as to general types of errors made, but who were not required to adhere to a constant procedure in grasping and throwing the rings; Group C included 4 children who, in addition to a preliminary demonstration and verbal criticism similar to that given to Group B, were taught to follow a certain definite procedure in throwing and were not allowed to experiment with any other methods. It was found that the amount of improvement shown during the 50-day period averaged least for the children in Group A, only slightly higher for those in Group B, but very much greater for the children in Group C. Only one of the children in Group B showed clear evidence of profiting by the verbal instruction or suggestions given.

3. The reliability of the score on a single day's performance was found to be approximately .50. The reliability of the score on a ten-day segment of the curve averages approximately .90. The reliability of the total performance during the 50-day period, computed according to a method recently proposed by Stone and Nyswander, is .933 for the entire group of 20 cases.

4. Practically no relationship was found to exist between initial status and gain.

5. A small negative correlation (−.349) was found between total score and IQ.

6. In each of the three groups, the boys exceeded the girls in mean total score earned during the 50-day period. While the mean gain in score made by the girls was very slightly greater than that earned by the boys, they were still considerably behind the boys at the end of the 50 days' practice.

7. Improvement in skill occurs in the course of the daily practice periods. The last five of the twenty trials are 13.6 per cent more likely to be successful than are the first five.

8. A study of the effect of variations in the distribution of the periods of practice as such variations were produced through the operation of week-end and other absences was inconclusive. There is, however, a suggestion, particularly when the curves for the individual children are analyzed separately, that the effect of interruption of practice may be a differential one, varying according as the particular type of habits which are being formed at the time of its occurrence are in general favorable or unfavorable. Further study of this point is needed.

9. The effect of the establishment of a motor orientation or 'set' was studied by means of a comparison between the sequences of successes actually found for the ten children whose learning curves showed the greatest amount of improvement during the experimental period with the ten showing little or no improvement, and with the chance expectancy. While the differences were not great, it was found that in six of seven determinations the better learners showed a tendency toward the grouping together of successes which was in excess of the chance expectancy, and that this tendency was most marked on the days with the greatest number of successful throws. The poorer learners showed only a slight departure from the chance expectancy at any level of performance. An additional study of this factor is now in progress.

10. The effect of the pleasurable emotion aroused by success was shown in a decidedly greater tendency to throw beyond the mark in the case of those errors immediately following success. This characteristic was shown by 17 of the 20 subjects, while in the remaining 3 cases the differences were

negligible. For the entire group of 20 subjects, the difference in the percentage of overthrows following success as compared to the percentage among the remaining errors was 5.47 times the standard error of the difference. A small but unreliable correlation (+.325) was found between the extent of this tendency shown by the individual children and teachers' ratings on general emotional responsiveness as displayed in the nursery school.

11. Analysis of the individual learning curves by means of a study of the daily record sheets appears to throw considerable light upon a number of factors influencing success. Among these may be mentioned; (a) emotional factors, including not only changes in motivation but over-confidence or undue caution, (b) the setting up of constant forms of undesirable motor procedure with subsequent deterioration in performance as practice in error continues, (c) false associations of cause and effect, as shown in the case of the child who tried to correct a habit of throwing downward instead of forward by standing on tiptoe and raising the rings higher in the air before throwing, (d) peculiar associations of meaning attached to verbal expressions which to the child are indicative of a generally desirable form of behavior, such as making "trying hard" synonymous with "throwing with great violence" or "being careful" with "being very gentle or cautious," (e) incorrect focussing of attention, as shown when a child looks at his arm or hand instead of at the goal when throwing, and (f) frequent random changes in procedure without adhering to any one practice long enough to develop control of the particular motor pattern involved. There are indications that the optimal distribution of practice is not an absolute matter, which can be expressed in final and definite terms as daily, twice daily, or on alternate days, but rather that greatest efficiency may perhaps be gained by appropriate interruption of practice at times when the setting up of undesirable habits appears to be retarding progress. The negative as well as the positive aspects of learning must always be kept in mind.

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READING AND LEGIBILITY OF CHINESE CHARACTERS

BY SIEGEN K. CHOU[1]

Stanford University

I. Influence of Reading-Direction and Character-Position Upon Speed

Three general conditions are involved in the psychology of reading, *peripheral* or physiological, *central*, and *external* or typographical. Investigations on the legibility of Western languages are extensive and numerous (12, 13, 27). All the intrinsic and extrinsic factors have been thoroughly scrutinized from various angles by many investigators, so that we now have sufficient knowledge to guide us in most of the practical phases of printing. But the legibility of Chinese characters has never been touched upon by the various Chinese investigators of the psychology of reading Chinese (5, 6, 18, 23–25, 27–31), who were mainly engaged in the problem of relative speed of horizontal and vertical reading. No amount of research can yield any final result until we faithfully and patiently analyze the make-up of the characters themselves in so far as it conditions legibility. This can be most adequately done first by a genetic approach to the history of etymology and its evolution, secondly by an inquiry into the nature of the concept-symbol of Chinese as distinct from the sound-symbol of the Western languages and thirdly by an elaborate dissection of the mechanics of construction of current forms in order to make a just estimation of their influence upon the perceptual processes of reading. Earlier discoveries by Cattell (2–4) and Dodge (9–10) of the importance of the total word-

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unit, by Goldscheider and Müller (11) and Zeitler (34) of certain determining and dominating parts in every word, and by Messmer (21) and Huey (15) of the dependence of the total character of a word upon the width, height and geometrical form of the letters, and of the varying importance of the first and last, upper and lower halves of a word, should point in the right direction for making a really pertinent analysis of the corresponding effects and differences in the case of the Chinese language. The legibility of Chinese differs from the legibility of Western languages mainly but radically in the peculiarities of the language itself and in the specific conditions that must be fulfilled. The characters are of uniform dimensions; they are not alphabetic but are composed of individual strokes and may be compounded; they can be placed either vertically or horizontally; punctuation may or may not be used; there is nothing that corresponds to the capitals of the Western languages. All these are peculiarities to be noted and specific conditions to be taken into consideration. Since Chinese is a pictorial and symbolic language, its legibility can be studied from the perceptive point of view and aside from the meaning which the individual characters may convey. In fact, such a purely perceptual study is pertinent because, for example, by applying it to foreigners[2] who have no knowledge at all of the meaning of the individual characters, the relative legibility of the latter in isolation or grouped in various sequences and relative positions to one another can best be determined, not unlike the nonsense syllables in memorial experiments. Here we have a perfect experimental control that is free from the habit and 'meaning' factors. Hence much more conclusive results should be obtained from a single study than from many elaborate studies using Chinese subjects. Wylie (33) actually concluded that the Chinese characters are good material for psychological experiments at large. Hull (16) and Kuo (19) both used Chinese characters in their studies on the evolution of concepts and on inductive inference. Sun (26) and McCartney (20) noted the symbolism

[2] Cf. L. S. Tsai & E. Abernethy, The psychology of Chinese characters, this JOURNAL, 1928, 11, 430–442. This article appeared while the present paper was in press.

of the Chinese written language and its relation to psychoanalysis.

It is the contention of the present writer [3] that the problems of the psychology of reading Chinese can be adequately or hopefully solved by a shift of attention to the legibility of the language itself. The intrinsic factors that determine legibility in the Western languages also determine it for Chinese; only there are more complicated factors that do not influence the former. Some of the more important problems of reading and legibility in Chinese are (1) form or individual differences of the characters, (2) size of the character, (3) style of the character, (4) position of the character in the group, (5) spacing between characters, (6) length of line, (7) leading, (8) appearance of Arabic digits or foreign words, (9) punctuation and special marks, (11) index system and (12) hand-writing. Horizontal and vertical arrangement is only one of many problems.[4]

Horizontal or Vertical Arrangement. This is the last and the most important factor that influences the legibility of Chinese characters; but not until other factors have been thoroughly studied can a definite conclusion be reached. Eye-movements (22–25), tachistoscopic exposures, reading rate (30–31), and cancellation tests (5), all suggest that the vertical is better than the horizontal. Since this problem is of interest not only to the Chinese, whose written unit happens to be a perfect square and hence can be placed either horizontally or vertically, but also to the Western people (13, 14, 17) as well—since signboards, back-bone titles of books (1, 12) and labels are not infrequently printed with the letters one above the other—, an analysis of the possible factors involved and their influences upon the two manners of reading is imperative. There are the physiological factors of the relative position of the two eyes, retinal field of clear vision, peripheral

[3] An article by Dr. Wei Ai entitled Psychological studies of Chinese characters appeared in the *Chinese Educ. Rev.* (1928, 20, no. 4, 5) just as this manuscript was ready for publication. It fulfills a part of the earlier anticipations of the present writer.

[4] This paper, the first of a series on reading and legibility of Chinese characters by means of a new technique, aims to settle once for all the problem of horizontal and vertical arrangement.

vision, lid and eye movements, muscular mechanism of the eyeballs and convergence and accommodation. There are the psychological factors of preference and the common optical illusion of vertical and horizontal lines. Again, there are the typographical factors. Of these, total form and the configuration of characters or letter-words in the two arrangements are most significant.

The full appreciation of the effect of these various factors upon the ways of arranging reading material can be brought to light only by an extensive experiment on very young school children, extending over a very long period of time, involving reading practice in the two arrangements, using control groups, and, finally, measuring the practice effects. Any attempt to solve the problem by using adult subjects—Chinese for reading horizontally and foreigners vertically—is frankly measuring the effects of habit and training, and these are bound to obliterate all other possible factors. Shen's (25) qualitative results and his quantitative differences in pause-frequency, pause-duration and regressive fixations, cannot be safely accounted for by saying that the mechanism of eye-movement is particularly adaptable for vertical reading unless there is counter-proof that this is also true in foreign subjects who are not accustomed to that manner of reading, because we do not know whether these characteristic differences are the conditions or the *results* of training and habit.

The Problem

Three Propositions. The influence of habit and training upon the reading of Chinese in the common vertical arrangement should be neither overestimated nor underestimated. It has to be taken at its face value. There is no doubt that the Chinese language was devised, intended and better adapted for vertical reading. The mere fact that it can be arranged in rows as well as in columns, because the individual characters happen to form a square, need not obliterate the distinction between what is entirely an accidental advantage and hence a matter of expediency (if the tendency is to adopt the horizontal arrangement) and what is inherent and intrinsic in etymology,

evolution, mechanics and architecture of the construction of the characters themselves. The real problem is how far the general sequence of one character, following the other in rows, would alter the total configuration in columns and how much this alteration, if any, would affect the speed of reading. This can be put as follows in the form of three propositions.

(1) If, keeping the position of characters constant, the effect of changing the direction of reading upon the speed of reading Chinese is less than the effect of altering the position of characters while keeping the direction of reading constant, we shall have conclusive evidence that the total character of the relative positions of characters in a column or a row is more important and significant than the general direction of reading.

(2) If, although the direction of reading within the line is neither that of the Western languages nor that of the original Chinese usage, this direction is nevertheless the habitual direction of progress from line to line and hence is better than one that is neither the direction of reading within the line nor the habitual mode of progress from line to line, we shall have every reason to conclude that habit and training are all-important for the difference and that all possible differential factors will be obliterated.

(3) If the direction of reading, in so far as it affects at all the speed of reading Chinese, affects it only by virtue of the temporal-spatial sequence of the characters in the group *during* the perceptual process of reading, we shall be justified in discouraging any attempt to ascertain whether vertical or horizontal reading is more efficient in those who had already been dominated by one particular temporal-spatial sequence.

As the Chinese characters are pictorial and non-phonetic and are, in most cases, uniform, compact and symmetrical, it may be that, by turning them upside-down or by tilting them to the right or to the left, the perceptual process would not be so much hindered as it would in Western alphabetic languages. In other words, the recognition of a character in its four possible positions (upright, upside-down, tilted to the right or tilted to the left) may not cause so much distraction

as when we read an English word in the corresponding positions; but the differences will surely be great enough to make a comparison. It is also obvious that the general direction of reading may be either downward or upward in case of the vertical, and either rightward or leftward in case of the horizontal without exciting much novelty. Thus we have four ways of placing a character, and characters placed in each of these four ways (to form a column or a row) may be read in four directions. This gives us a fine isolation and variation of experimental control to test the above three propositions.

Letting capital letters denote the directions of reading and small letters the positions of individual characters in the group, the problem is specifically to compare the speed of reading in the following sixteen possible combinations of reading-direction and character-position:

(5) Du—Upright characters
(6) Dd—Upside-down characters
(7) Dr—Characters tilted to the Right
(8) Dl—Characters tilted to the Left
All to be read downward, i.e. from top to bottom

(1) Uu—Upright characters
(2) Ud—Upside-down characters
(3) Ur—Characters tilted to the Right
(4) Ul—Characters tilted to the Left
All to be read upward, i.e. from bottom to top

(9) Ru—Upright characters
(10) Rd—Upside-down characters
(11) Rr—Characters tilted to the Right
(12) Rl—Characters tilted to the Left
All to be read rightward, i.e. from left to right

(13) Lu—Upright characters
(14) Ld—Upside-down characters
(15) Lr—Characters tilted to the Right
(16) Ll—Characters tilted to the Left
All to be read leftward, i.e. from right to left.

Method and Procedure

Methodological Considerations. Earlier studies by Kao and Cha (18), Chen and Carr (6) and Tu (29–31) in comparing the speed or rate of reading in the two arrangements were

performed by the usual method of recording the total time in reading a passage and then finding the average rate in terms of words per second by dividing the total number of words by the total time. While this method may suffice for all practical purposes, it is most likely to be inadequate for eliciting the effects of a factor that is in all probability very delicate. Moreover, the combined effect of interest, attention, mental set, practice, etc., may entirely over-rule the factor of arrangement and so make the result more or less a matter of chance. On the other hand, the perception-span method of extremely brief exposures by the tachistoscope is not only unnatural but far-fetched.

As early as 1907, Dodge (10) decried the indiscriminate use of the tachistoscopic technique. "The tendency to reduce the physical exposure time to a minimum (he says) wherever the aim is to present an adequate exposure of the simplest kind is a methodological mistake, based upon a psychophysical misconception. It introduces unusual conditions altogether foreign to the natural fixation pause and leads, or may well lead, to a distorted analysis of the processes of apprehension; making the conclusions, in so far as they are referred to normal perception, not merely valueless but false. . . . Visual perception from a threshold exposure may be and indeed must be quite a different matter from normal visual perception . . . and the results of the former should be applied to the latter only where there is clear justification of the analogy. . . . Anything approximating a threshold exposure, instead of simplifying the consequent psychological process, really complicates it and renders it more uncertain. . . . The only exposure whose results will apply directly to normal processes is that which, under the given experimental conditions of illumination, will permit a full and uniformly cleared-up impression. For this exposure we still have a right to the superlative implied in the word 'tachistoscopic,' since we refer not to the most rapid excitation, but to the most rapid VISION which is really cleared-up and adequate."

Apparatus. This 'rapid vision' is made possible by a new *quadrant tachistoscope* (7) specially designed for this purpose, a complete description of which appears in this issue. It consists essentially of a shutter window in the form of four aluminum quadrants (hence the name), each of which can be opened separately in two directions, namely, the upper right quadrant either to the right or upward, the upper left quadrant either to the left or upward, the lower left quadrant either to the left or downward, and the lower right quadrant either to the right or downward. Any pair of the four quadrants can be moved jointly by simply turning a switch so that the window will open either horizontally or vertically as desired. The quadrants are held together by springs and are electromagnetically operated by eight small solenoidal magnets. A slight pressure upon a key will open any two opposite pairs of the shutters, and these quickly close as soon as the finger is released. Behind the shutters, cards bearing seven printed Chinese characters, arranged either vertically or horizontally, drop down automatically one at a time for reading, from a specially designed card-holder held above the window. After the reading, the card drops down again by its own weight to a similar card-holder below the window. This changing and releasing operation of the

card is controlled by the experimenter by simply pushing a lever, while the subject himself opens and closes the shutter window by pressing a key. The time for reading the seven Chinese characters on the card is marked by a stop-watch that registers 1/50 sec.

Reading Material. The specially printed material is on gummed paper from which the rows or columns of characters were cut by a trimming board and then pasted in the center of white stiff cards, 3 in by 3–5/16 in, to which size the tachistoscope is designed. Four series of material for the four directions of reading were printed, each with 8 selections of the seven Chinese characters put in each of the four positions, thus making 32 for every series. (See Fig. 1 for sample.)

1 is for reading from left to *right*
2 is for reading *downward*
3 is for reading from right to *left*
4 is for reading *upward*

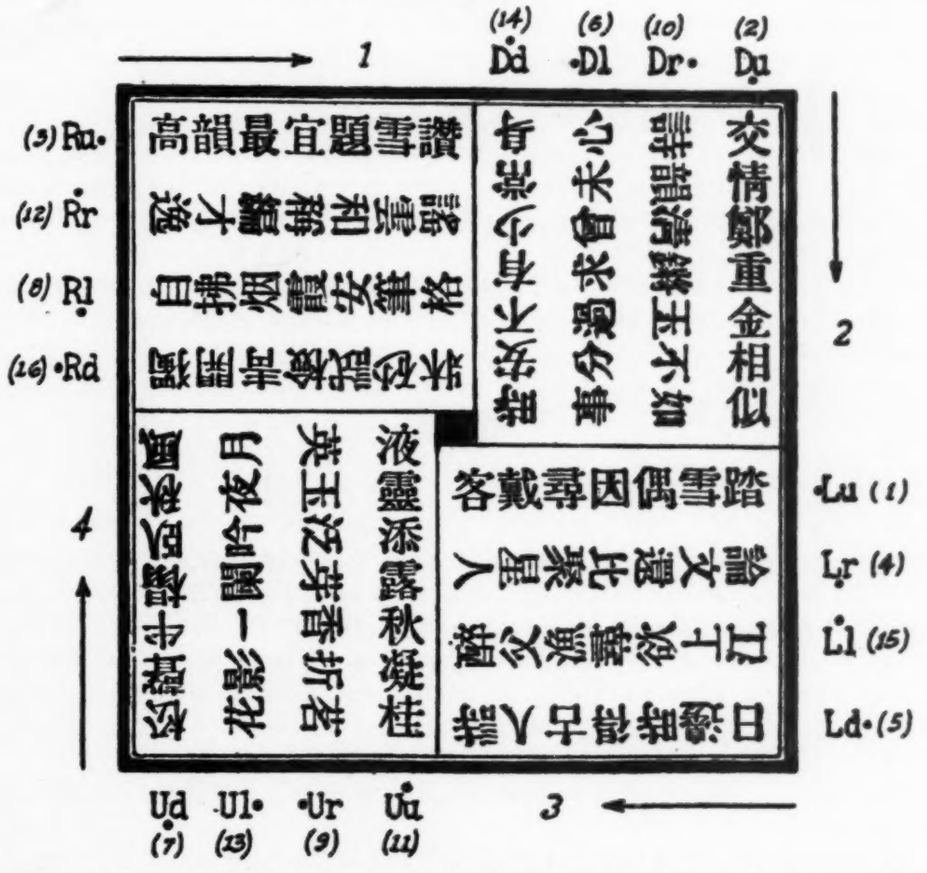


FIG. 1. The capital letters denote the direction of reading and the small letters denote the position of characters. u = upright, r = tilted 90° to the right, l = tilted 90° to the left, *d* = upside down. The dot signifies that in reading the eyes move from *that* side of the first character to the adjacent side of the next character. The small numbers in parenthesis beside the letters are the rank orders for the different manners of reading from the fastest to the slowest. See discussion of results below.

The materials are all couplets or poetical parallelisms from eminent poets or writers as collected in the *Everyday Encyclopedia* published by the Commercial Press, Shanghai. It is a usual custom of the Chinese to write couplets on rolls of paper to be hung on the

walls of study-rooms, bed-rooms and the drawing-room or parlor of the house, or on red paper to be pasted on all doors and renewed for every new year. Our selections are all adapted for the study-room. The following reasons and cautions were in mind when the writer selected this particular form of sense-material. (1) In order to avoid the common prejudice of that group of Chinese students who are to serve as subjects in psychological experiments, for fear that nonsense material would perhaps create a cumulative impression that psychological experiments are just as nonsensical, sense material was used although perhaps nonsense material might have been better. (2) This particular form of couplet or poetical parallelism has the advantages of a uniform length of seven characters and of assumably equal or unequal familiarity to the Chinese observers. (3) Selections were made only of those that have no rare or unfamiliar words, judging from the writer's knowledge or estimation of the vocabularies of Chinese students, and of those whose meanings can be grasped by the majority of them, judging also from the writer's knowledge of their training in the Chinese language and literature.

Procedure and Subjects. The four series of material were presented in chance order to 12 subjects, all Chinese students at Stanford, in four sittings at intervals varying from 5 to 21 days. Of the 12 subjects, one did not finish (serving only one sitting) and the rest took from 20 to 41 days to complete the entire experiment.

The order of presentation of the 4 series as a whole was changed in every sitting so that every series was given a chance to occupy every position in the order of presentation that we might equalize the practice effect. And in order to equalize the effect on the two horizontal and two vertical series, the subjects were divided into two groups, the first 6 subjects reading the vertical series first and the last 6 the horizontal first. The actual order of presentation of the 4 series for the two groups in each of the four sittings is as follows.

Group	Sittings			
	1	2	3	4
I	DURL	RLDU	UDLR	LRUD
II	RLDU	DURL	LRUD	UDLR

Appointments with subjects for each sitting were made as nearly in the same hour of the day as possible, but owing to individual variations in free hours, some took the experiment in the morning, some in the afternoon, and a few late at night. During daytime, ordinary daylight was used; at night an ordinary 75-watt Mazda lamp. Both the amount of illumination and the reading distance were adjusted according to individual requirements so that the normal situation for reading was insured as far as possible.

Instruction. The following written instructions were given to the subject before every sitting.

> Look attentively at the cross of the window in the hood and at the same time keep your right index finger barely touching the key on your right. At the signal 'Ready, go!,' press the key down hard and hold it there. This will immediately open the window exposing 7 Chinese characters. Read aloud in your native tongue whatever is exposed, no matter in what arrangement, as quickly as you can. If you come to a word that you don't know how to pronounce, make a sound in place of it. Do not bother much about the meaning of what you read. As soon as you have pronounced the last word, quickly release the key. Never release the key while you are reading aloud. There are 4 series of 32 exposures each. In each series, about an equal number of exposures will be UPRIGHT, UPSIDE-DOWN, tilted to

the RIGHT, and tilted to the LEFT. Read as quickly as you can in every case. The first exposure in each series is intended for practice. The time elapsed from the opening of the shutter to the utterance of the last word in every exposure will be marked by a stop-watch in fiftieths of a second. I will tell you which series you are going to read and how to read it at the beginning of every series. Try to use the same attitude and method in reading throughout the whole experiment.

Then the subject was told the particular manner of reading each series, depending upon the series and the sitting, *i.e.* either from top to bottom, from bottom to top, from left to right or from right to left, as the case might be. Attention was called to the following points in the instruction.

(1) The subject rather than the experimenter is required to open the shutter because by so doing the fullest amount of attention is secured as the subject would not press down the key unless he is ready to read.

(2) The key is pressed down all the time during reading and is not to be released until the subject finishes his reading rather than having a single downward pressure for opening, letting the shutter stay open or the experimenter close it, because this new kind of reaction actually keeps the subject on the alert all the time, a slight roaming of attention being sufficient to break the current, thus closing the window and hence destroying the field of view. This might constitute a distraction method but it resembles more closely Woodrow's (32) *detraction* method.

(3) Only speed is required or rather necessitated in this experiment, hence the instruction to make a sound in place of any word that the subject cannot pronounce and also not to bother much about the meaning of the reading material, although every caution had been made in selection to exclude unfamiliar words.

(4) The reading-time is taken from the opening of the shutter to the utterance of the last word in each exposure rather than to the closing of the shutter because after some preliminary trials it was found that some tend to let go the key before they actually finished reading and others not.

(5) A stop-watch rather than a chronoscope is used in the timing because the reading varies from slightly less than a second to six seconds. The timing is done by one experimenter throughout the entire experiment.

(6) Special attention is called to keeping constant the attitude and method in reading throughout the whole experiment because changes of either would naturally affect the various series.

A rest of about one minute was allowed after finishing each series, during which the experimenter was engaged in changing the card-holders and setting the switch after the second series and in removing the cards. Estimations of the relative ease for reading the four series were obtained from each subject at the conclusion of the experiment.

There were 128 cards exposed to every subject during each sitting and four sittings to each of the 11 subjects that concluded the experiment, hence 5632 (= 128 × 4 × 11) reading-times were thus recorded covering a period of 67 days. Each sitting took, on the average, about half-an-hour.

Reading-Direction and Character-Position as Interdependent Factors that Influence the Speed of Reading Chinese

Speed. The *mean reading time* with standard deviations (in .02 sec) of 11 subjects in 4 sittings for 16 combinations of the various positions of 7 characters read in various directions ranges from 97.3 (in the case of direction Lu) up to 116.4 (in the case of Rd).

Table I

Mean reading time with standard deviation

Dir'n of reading		Position of characters u	d	r	l	All pos'ns	Vert. or Hor'tal
D	m	99.7 (2)	114.5(14)	110.7(10)	108.7(6)	108.4(2)	
	σ	*24.5 (7)*	*32.7(15)*	*26.6(10½)*	*27.9(13)*	*27.9(3)*	109.8
U	m	112.2(11)	108.8 (7)	109.6 (9)	113.8(13)	111.1(4)	*25.5*
	σ	*25.0 (8)*	*21.6 (3)*	*21.8 (4)*	*23.9 (6)*	*23.1(2)*	
R	m	99.9 (3)	116.4(16)	112.9(12)	108.9 (8)	109.5(3)	
	σ	*23.5 (5)*	*33.1(16)*	*30.2(14)*	*27.1(12)*	*28.5(4)*	106.9
L	m	97.3 (1)	106.0 (5)	100.4 (4)	114.7 (15)	104.6(1)	*25.8*
	σ	*19.2 (1)*	*25.8 (9)*	*20.5 (2)*	*26.6(10½)*	*23.0(1)*	
All dir'ns		102.3 (1)	111.4 (3)	108.4 (2)	111.5 (4)	**108.4**	
		23.5 (1)	*28.3(4)*	*24.8 (2)*	*26.4 (3)*	**25.6**	

Du, which is the habitual mode of reading the Chinese language, and which takes 99.7, proves to be only second to Lu, while Ru (which is the natural horizontal reading) takes 99.9 and is only the third fastest. On the other hand, although Ll takes 114.7 and is next to the last, Dd is only a little shorter (114.5), while Ld and Ud occupy the 5th and 7th places respectively. Lr is 4th, but Rr is only 12th and Rl 8th. Dl is 6th and Dr is 10th than which Ur takes even shorter time, although Uu is 11th.

The rank order is as follows; Lu, Du, Ru, Lr, Ld, Dl, Ud, Rl, Ur, Dr, Uu, Rr, Ul, Dd, Ll, Rd. If we take together D and U, which are *vertical* (V) readings, R and L, which are *horizontal* (H) readings, H takes 106.9 which is shorter than 109.8 for V.

These means are not very reliable since individual differences are great. This defect can be checked by a *paired comparison*, item by item, of the various directions of reading by all subjects.

Taking all positions together as a whole, the probability of D being faster than U is $26\frac{1}{2}:17\frac{1}{2}$, than R 24:20, but only 17:27 than L or, in other words, the chances are 27:17 that the latter

TABLE II

D:U	D:R	D:L	U:R	U:L	R:L
26½:17½	24:20	17:27	23:21	8:36	10:34

D	U	R	L
26.5	17.5	20	27
24	23	21	36
17	8	10	24
67.5	48.5	51	97

V 116 H 148

is faster than the former. The probability of U being faster than L may be negligible (8:36) but is (appreciably above chance; 23:21) faster than R. L is in all probability faster than R, the ratio being 34:10. Adding all three comparisons of each of the 4 directions together and combining D with U, and R with L, the probability for H being faster than V is 148:116 or 37:29.

A better idea of the interdependence of positions of characters and directions of reading in influencing the speed of reading the seven Chinese characters may be had by determining the *percentage advantage* in terms of difference in mean reading-time between these various comparisons among the 4 directions of reading for the 4 positions of characters and for all positions as a whole (Table III).

TABLE III

	u	d	r	udrl		l
L shorter than D	2.41	7.42	9.30	**3.50**	D shorter than U	4.48
L shorter than U	13.30	2.57	8.40	**5.84**	D shorter than R	.18
L shorter than R	2.60	.34	11.08	**4.48**	D shorter than L	5.84

In reading u, d, and r characters and in reading all positions as a whole, L has an advantage over all the other 3 directions of reading, which D has only in the case of the l characters. In reading all positions as a whole, the figures tend to differ very little, L being 3.50% shorter than D, 5.84% than U, and 4.48% than R. In reading the l characters, D takes 4.48%, 0.18%, and 5.84% less time than U, R, and L respectively.

The *rate of reading* in terms of characters-read-per-second can be easily calculated from the mean times for the 16 combinations. It is found that Lu, which takes the shortest time

(97.3), yields the highest rate of 3.59 words read per sec, while the lowest rate of 2.98 words per sec is found in the case of Rd (116.4). The mean rate of all the 16 combinations is 3.23. Du and Ru have a rate of 3.51 and 3.50 respectively, which correspond to Tu's figures, 4.17 and 3.61, in oral reading for speed (30). The discrepancy is explained by the fact that Tu had subjects read passages, while in this experiment subjects read in units of seven characters and intermittently only. Considering the various directions of reading as a whole, D and U are less consistent than R and L as evidenced by the fact that (see Table IV) out of a possible 44 perfect agreements of the objective ranks of reading time among the various positions within any one direction of reading, D has only 5 and U 6 while R and L have 15 and 18 respectively. But subjective estimations and objective ranks generally agree in the case

TABLE IV

	D	U	R	L
Consistency between sittings	5	6	15	18
Agreements between objective results and estimates	16	11	28	16

of D and L, all having 16 perfect agreements out of a possible 44; but U has less than half the perfect agreements of R, the former having 11 and the latter 28. In general, the Os' subjective estimations tend to agree more with the average ranks of objective results than the objective ranks agree with themselves in successive sittings.

If we count the most frequent objective rank of the 4 positions of characters, as ascertained by the mean reading time within any one direction of reading in all sittings of all subjects, and compare it with the corresponding subjective rank, we find that for D and R there is perfect agreement and for L there is agreement only in u and r characters while for U there is no agreement at all among the 4 positions.

TEMPORAL-SPATIAL SEQUENCE AS AN EXPLANATION OF THE INTERDEPENDENCE OF READING-DIRECTION AND CHARACTER-POSITION IN INFLUENCING THE SPEED OF READING CHINESE

Results. The first result of our experiment upon the interdependence of character-position and reading-direction is

that by *altering jointly the position of characters and the direction of reading the speed of reading Chinese is little impaired as compared with the presumably detrimental effect that would probably be produced on reading speed if any of the Western languages should be similarly altered.* This contrary effect found in the case of Chinese characters indicates that the experimental procedure adopted in this experiment is not so absurd as it at first seemed to be. Thus when seven Chinese characters standing upright require 97.3 × .02 or 1.95 sec to read from right to left (Table I), the greatest detrimental effect is produced by turning the characters upside-down and reading in the other direction, as evidenced by the fact that 116.4 × .02 or 2.33 sec are required. In other words, by altering jointly the position of the characters and the direction of reading, the greatest detrimental effect on the speed of reading Chinese is only 19.63%. When upright characters are read in the habitual downward direction it requires 99.7 × .02 or 1.99 sec; by altering the position of characters and direction of reading in the same manner, the speed of reading is decreased only 16.74%, even less than in the former case.

The second result of this experiment is that *the position of the characters is a more important factor in determining the speed of reading Chinese than is the direction of reading.* When upright characters are read in all directions they take 102.3 × .02 or 2.05 sec (Table I); but when all positions are read in the same downward direction, they take 108.4 × .02 or 2.17 sec (3.76% longer). This is further substantiated by the fact that the average time of the other three unusual positions read in all directions is 8.1 (× .02) or 7.92% longer than 102.3 (×.02) for the normal upright position read in all directions; while the average time of the other three non-habitual directions of reading the characters in all positions is exactly the same 108.4 (× .02) for downward reading in all positions.

This outcome seems to support the first proposition set forth (see page 160 above); namely, that, *position of characters held constant, the effect of changing the direction of reading upon the speed of reading Chinese is less than the effect of altering the*

position of characters while keeping the direction of reading constant.

The third result of this experiment is that *discarding the two cases of reading upwards and turning characters upside-down because they have no practical significance, it is faster to read in all positions, except those tilted to the left, from right-to-left than from left-to-right, and that it is better to tilt the characters to the right for upward-and-leftward reading and to the left for downward-and-rightward reading, although characters tilted to the right generally are better for all directions of reading.*

Thus leftward reading takes 104.6 (× .02) on the average for reading all positions of characters while rightward reading requires 109.5 (Table I), the former being 4.48% shorter (probability by paired comparisons = 97:51). Characters tilted to the right take 108.4 (× .02) on the average for all directions of reading while characters tilted to the left require 111.5, the latter being 2.86% longer (probability by paired comparisons = 26.5:17.5).

This result seems to support our second proposition; namely, that *although the direction of reading within the line is neither that of the Western languages nor that of the original Chinese usage, it is nevertheless the habitual direction of progress from line to line and hence is better than one that is neither the direction of reading within the line nor the habitual one of progress from line to line.*

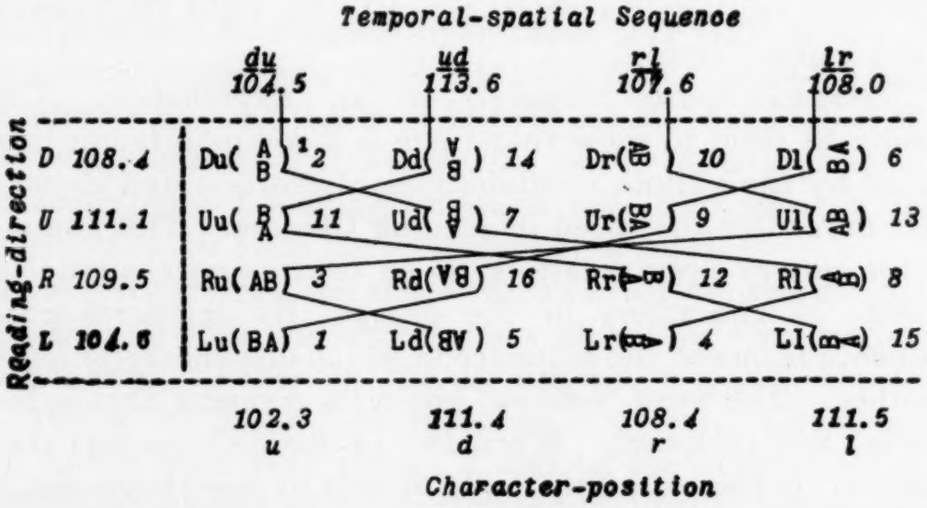
The fourth result of this experiment is *that something besides position of character and direction of reading determines most readily the speed of reading Chinese.* It is easily seen that downward reading upright characters (Du) ranks 2d (Table I). This is only natural because it is the habitual reading. But when the characters are turned upside-down and are read upward (Ud), it still ranks 7th, even better than rightward reading with the characters only tilted to the right (Rr). Furthermore, with the characters tilted to the right, leftward reading (Lr) ranks even higher (4th) while with the characters tilted to the left, rightward reading, (Rl) ranks only 1 rank lower (8th). On the other hand, upward reading upright characters (Uu) ranks 11th. This is also natural

because we seldom read upwards. But when the characters are turned upside-down and read downward (Dd), it ranks only 14th. Furthermore, with the characters tilted to the left, leftward reading (Ll) ranks even lower (15th), although rightward reading characters tilted to the right (Rr) ranks 2 ranks higher (12th).

Temporal-Spatial Sequence as an Explanation. These results all seem to show that there is a common factor introduced by the various combinations of position and direction that influences the speed of reading Chinese. This common factor proves upon analysis to be the temporal-spatial sequence of characters in the group. By temporal-spatial sequence is meant the sequence in which one character *follows* another. The word 'follows' implies a meaning that is both spatial and temporal. When two or more characters stand together on the page either side-by-side or one-above-another they are only 'spatially' *following* one another. But as soon as, and so long as, they are the object of perception, that is, as soon as, and so long as, there is somebody perceiving them they are not only 'spatially' *following* one another, but 'temporally' as well.

Denoting the top or upper side of a character by *u*, the bottom or down side by *d*, the right side by *r*, and the left side by *l*, it is evident that downward reading has a temporal-spatial sequence *du*, upward reading *ud*, rightward reading *rl* and leftward reading *lr*. This is meant to say that in downward reading the perceptual process is *from* the bottom of one character *to* the top of the next character, in upward reading *from* the top of the character *to* the bottom, in rightward reading *from* the right *to* the left, and in leftward reading *from* the left *to* the right. It is conceivable that should any one of these temporal-spatial sequences be altered by changing the position of the characters, the speed of reading would be impaired or improved, no matter in what direction the reading is carried on. This is what actually happened. The various combinations of reading-direction and character-position yield different speeds; but it is due to these temporal-spatial sequences that some of the peculiarities noted in the last

section were exhibited. The following checkerboard arrangement shows the relation between the temporal-spatial sequence and the various combinations of reading-direction and character-position.



For suggesting this direct way of representing the various combinations of character-position and reading-direction, I am indebted to Dr Eugene Shen.

Those that are on the same horizontal rows are in the same direction, those in the same vertical columns have the same position of characters, and those connected by lines are neither in the same direction of reading nor have the same position of characters, but are in the same temporal-spatial sequence. It was previously noted that Du, Ud, Rl, and Lr all rank comparatively high among the 16 combinations. This is explained by the fact that they are all read in the same habitual temporal-spatial sequence (*du*), *i.e.* from the bottom of one character to the top of the next. On the other hand, Dd, Uu, Rr, and Ll all rank pretty low because they are all read in the opposite temporal-spatial sequence, *i.e.* from the top of one character to the bottom of the next, which is very unusual. The average time of the three unusual temporal-spatial sequences, namely, *ud*, *rl*, and *lr*, is 5.2 (× .02) or 4.98% longer than the habitual sequence (*du*).

Normal		Unusual		Per cent Increase
D	108.4	URL	108.4	0.00
du	104.5	*ud rl lr*	109.7	4.98
u	102.3	d r l	110.4	7.92

Relative effects of character-position, reading-direction and temporal-spatial sequence

The above figures summarize the comparative effect of direction of reading, temporal-spatial sequence of characters, and position of characters upon the speed of reading Chinese. By keeping the direction of reading constant while varying the temporal-spatial sequence and position of characters, the normal downward reading requires a longer time than holding either the normal temporal-spatial sequence or the normal position of characters constant while varying the other two factors. This shows that direction of reading is a relatively less important factor than either temporal-spatial sequence or position of characters. Likewise the temporal-spatial sequence of characters is less important than the position of characters, which is the most important factor of all since the normal upright position yields the shortest time in spite of the fact that both the direction of reading and the temporal-spatial sequence of the characters are heterogeneous. This is made more significant by the fact that the average time of the other three unusual directions of reading when kept constant, with variation of the other two factors, is exactly the same as for the normal direction of reading under the same circumstances; but the average times of the other three unusual sequences and three unusual positions of characters are increased 4.98% and 7.92% respectively.

This fifth result seems to support our third proposition set forth above; namely, that *direction of reading, in so far as it affects at all the speed of reading Chinese affects it only by virtue of the temporal-spatial sequence of characters in the group during the perceptual process of reading and that any attempt to ascertain whether vertical or horizontal reading is more efficient in those who have already been dominated by one particular temporal-spatial sequence is fruitless.*

Summary and Conclusions

The rôle of habit and training in the traditional vertical reading of the Chinese language has been demonstrated by reading in four directions (up and down in the vertical, right

and left in the horizontal) and by the use of four positions of seven Chinese characters, upright, upside-down, tilted to the right and tilted to the left. Three questions were asked: (1) which is the more important and significant factor, reading-direction or character-position? (2) Does the general direction of progress from line-to-line in the habitual vertical reading exhibit any appreciable effect on the horizontal directions of reading within the line? (3) In what sense or by virtue of what principle does reading-direction influence the speed of reading Chinese?

Eleven Chinese subjects completed in 4 sittings 4 directions of reading 8 selections for each of the 4 positions of 7 Chinese characters, yielding 5632 recorded reading times in fiftieths-of-a-second by means of a new *quadrant tachistoscope*. The 8 selections yielded 176 mean reading times from which five general conclusions were drawn as follows.

(1) By altering conjointly the position of the characters and the direction of reading, the speed of reading Chinese is impaired only 19.6% in the extreme case. This is when leftward reading of upright characters is changed to rightward reading of characters that are upside-down. The change from the normal downward reading of upright characters to the latter is even less (16.7%).

(2) Position of the characters is a more important factor in determining the speed of reading Chinese than the direction of reading, because the normal downward direction of reading all positions takes 3.8% longer time than all directions of reading the same upright characters. Furthermore, the average time of the three unusual positions of characters, read in all directions, is 7.9% longer than that for the normal upright position read in all directions; while the average time of the other three non-habitual directions of reading all positions of characters is exactly the same as that for downward reading in all positions. This answers the first question.

(3) It is faster to read in all positions, except those tilted to the left, from-right-to-left than from-left-to-right and it is better to tilt the characters to the right for upward-and-leftward reading and to the left for downward-and-rightward

reading; although tilting characters to the right is better for all directions of reading as a whole. Leftward reading takes 4.5% shorter time with a probability of 97:51. Characters tilted to the left take 2.7% longer time, with a probability of 53:35. This answers the second question.

(4) The interaction of reading-direction and character-position gives rise to a third factor which may be called temporal-spatial sequence of the characters-in-group *during* the process of reading. By temporal-spatial sequence is meant that sequence in which the saccadic movement of the eye during the perceptual process of reading traverses *from* one side of one character *across to* the adjacent side of the next character. This crossing-over of directional attention is perhaps the essential thing in all perceptions of successive objects of a pictorial nature. It is only a truism to say that the uprightness of a Chinese character determines this crossing-over of directional attention. In other words, the normal habitual temporal-spatial sequence is *from* the bottom of one character *to* the top of another, irrespective of either the position of characters or the direction of reading. Thus the average time of the three unusual temporal-spatial sequences, namely, from the top of one character to the bottom of the next, from the right of one character to the left of the next and from the left of one character to the right of the next is 4.98% longer than the habitual normal sequence, namely, from the bottom of one character to the top of the next. This answers the third question.

(5) So far as speed of reading Chinese is concerned, reading-direction is the least important conditioning factor. When it affects the speed at all, it affects it only by virtue of the temporal-spatial sequence created through the interaction between it and character-position, which is the most important conditioning factor.

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A QUADRANT TACHISTOSCOPE FOR STUDYING THE LEGIBILITY OF CHINESE CHARACTERS

BY SIEGEN K. CHOU [1]

Stanford University

The instrument presently to be described is similar in its general function to the Kuhlmann (8) and the Dearborn-Langfeld (1) forms of exposure apparatus designed for moderately brief time-exposure. It may therefore be conveniently classed with the tachistoscopes, certain forms of which have long been used by psychologists for the measurement of short times. For various instruments designed to provide relatively long exposures we may adopt Esper's [2] term *bradyscope* (5). Bradyscopes and tachistoscopes belong to the same general class since they are all apparatus for exposing perceptual material for experimentation under temporal control.

Five types of bradyscope used for memorial presentation may be distinguished; (i) the *drum* type of Schumann (13) and Meumann (10), later modified to a 'step-down' form by G. E. Müller (12), (ii) the *fall* type of Minnemann (12) and Kuhlmann (8), (iii) the *disc* type of Ranschburg (11, 12), Wirth (17) and Lipmann (7), (iv) the *booklet* type of Baird (6) and Schulze (12), and (v) the *endless-band* type of Wirth (18), Wohlgemuth (14) and Esper (5).

As Galileo was first (1609) to describe and exhibit in complete form the telescope and hence was conventionally known as its inventor, although it had been known for a long time before him, so we may credit the invention of the tachis-

[1] The construction of the tachistoscope was financed by the Thomas Welton Stanford Fund for Psychological Research. Constant encouragement and support from Professor Walter R. Miles have been a continuous incentive. Helpful suggestions have come from Mr. F. D. Banham, Mechanician Shop, Stanford University. Mr. Chien P'ei has taken the pictures of the tachistoscope.

[2] Esper's particular type of bradyscope is used for the exposure of verbal, graphic and pictorial material to be memorized.

toscope to Volkmann in 1859 (15). Four main types were evolved in its almost seventy years of development; the Wundt *gravity* type (20, 21), the Wirth *disc* type (16), the Dodge *mirror* type (2) and the *spring* and *camera shutter* type (1, 9). All these types make use either of a moving field, of a moving screen or of momentary illumination.

Our *quadrant tachistoscope* belongs to the same class as the Dodge *drop exposure* apparatus (4) for reading reactions and it might therefore be classed with the bradyscopes. But since the exposure is also controlled for short durations by a simple attachment, it is perhaps legitimate to associate it also with the tachistoscopes. It was devised to fulfill certain definite requirements in the general study of the reading and the legibility of Chinese characters and in the more specific problem of the influence of reading direction and character position upon the speed of reading Chinese (pp. 156–177 above). These definite requirements are:

(1) The exposure of the reading material should approximate normal visual perception in reading.

(2) The opening and closing of the shutter in exposing the reading material for reaction should be capable of control either by the experimenter or by the subject. The time elapsed between opening and closing the shutter or the definite reading reaction is taken as a measure.

(3) The shutter or shutters should open either sidewise or in the upward and downward direction as the experimenter requires and this opening should be made quickly and at will so that both horizontal and vertical materials may be exposed as required in the entire field.

(4) The time of exposure should be capable of objective record by means either of a chronoscope or a short-interval stop-watch.

(5) The changing and releasing of the reading cards should be quick and automatic so that a large amount of exposure may be made possible during one sitting.

General description. Four views of the apparatus are shown in Plate 1. The front and back views are shown in Figs. 1 and 4 respectively of that Plate. Fig. 2 shows the front view from the side with the subject in position, while the back view from the side with the experimenter in position is shown in Fig. 3. All parts are consistently

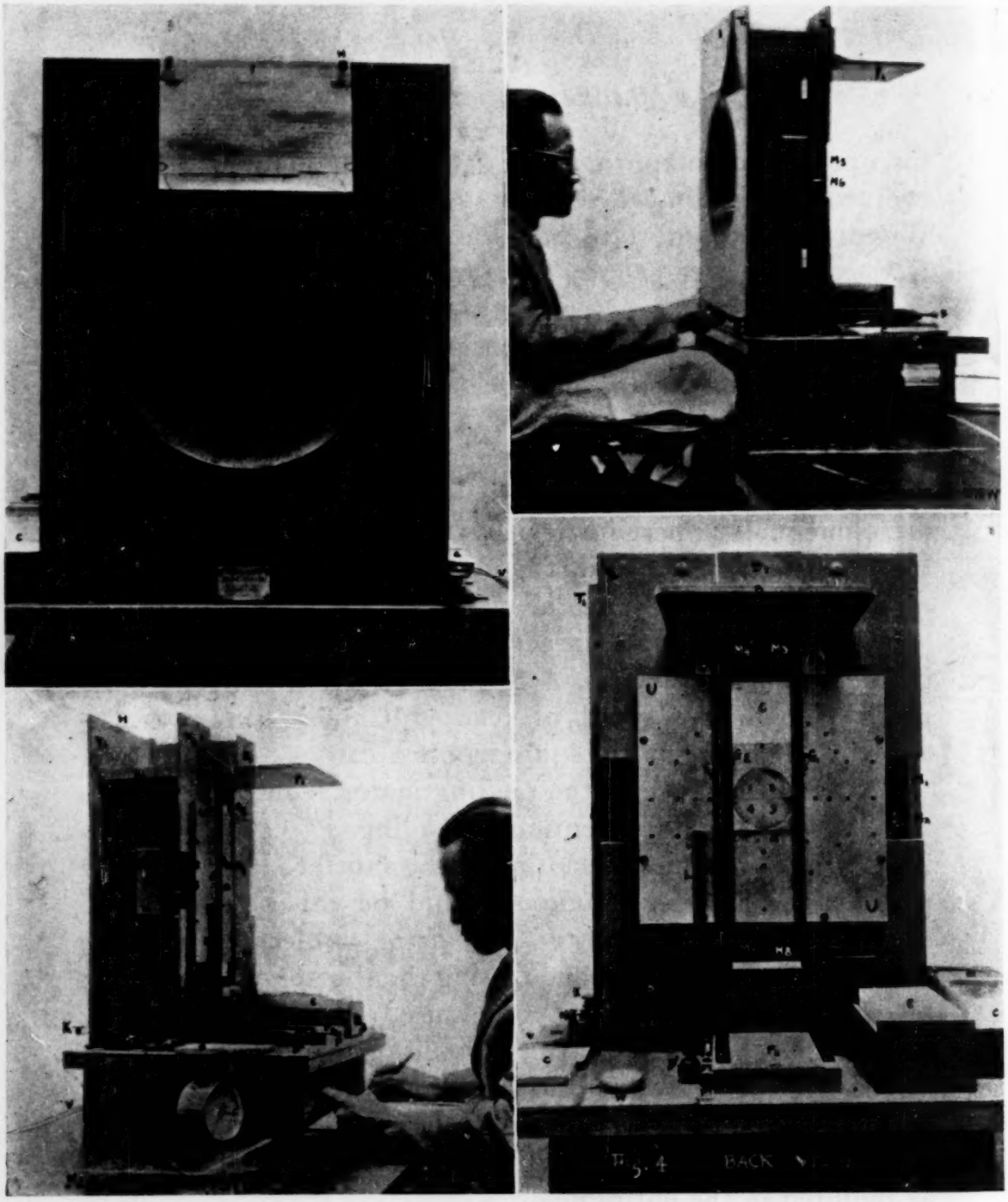

PLATE I—Legend

$B_{1,2}$	Upper and lower card-holders
B_3	Extra card-holder
B^1	Ordinary box for holding cards
b	Binding posts
C	Cards
D	Switch
D_1	Screw driver
E	Base
F	Rod for operating S by pushing knob
$G_{1,2}$	Guiding strips for the falling cards
H	Double hooks for hanging and changing I
I	Instruction card
J	Legs of X for attachment to T_2
K	Reaction key
L	Lever for operating card-release
$M_{1,2,\ldots}$	Solenoidal magnets
N	Boards for connecting T_1, T_2
O	Pivot of L
$P_{1,2}$	Upper and lower platforms for $B_{1,2}$
Q_3	Wooden frame for fastening $M_{5,6}$
R	Card-catcher and release
r	Convenient card-catcher (used in place of lower card holder)
S	Shaft for moving $B_{1,2}$ out to release and catch card
$T_{1,2}$	Front and back supporting frames
$t_{1,2}$	Pieces upon which $G_{1,2}$ are fastened
UU	Shutter unit
V	Wires leading to storage battery current
W	1/50-sec stop-watch
X	Funnel-shaped window
Y	Wooden box on which magnets $M_{1,2,\ldots}$ are fastened
$Z_{1,2}$	Metal strips for fastening $T_{1,2}$ to E
1, 2, 3, 4	Quadrant shutters

labeled in the four views and are alphabetically listed in the legend. The whole apparatus is supported by two vertical supporting frames, T_1 & T_2, connected together on the top by a wooden horizontal board, N, and on the bottom by a similar piece on both sides. The frames rest on the base, E. The dimensions of the frames and base are all 18 in × 24 in. They are of regular 3/8-inch wooden panel. To the back frame, T_2, is fastened by 8 bolts the shutter unit, UU, immediately in front of which the wooden box, Y, without top or bottom, is also securely screwed to the back frame, T_2. On the four sides of the box, Y, are screwed four pairs of specially designed solenoidal magnets. The armatures of these four pairs of magnets are connected through a crank lever with the corresponding four quadrants of the shutter, 1, 2, 3 & 4, in the shutter unit, UU. The four quadrant-shutters (see front and back views) form a cross, the intersection of which serves as the pre-exposure fixation point. Each of the quadrants can be operated separately by its corresponding pair of magnets in two directions; the upper right quadrant (1) either right or upward, the upper left quadrant (2) left or upward, the lower left quadrant (3) left or downward, and the lower right quadrant (4) right or downward. Any pair of the four quadrants can be moved jointly by turning the switch, D, in the proper position so that the shutter will open either sidewise, making the window open in the vertical direction, or in the upward and downward direction making the window open in the horizontal direction, as desired.

The shutter unit. On Plate 2 is shown a diagram of the inner mechanism of the shutter unit, UU, together with the wiring and switchboard, S, that operate and control the shutters through the action of the four pairs of solenoidal magnets, M_1 & M_2, M_3 & M_4, M_5 & M_6, and M_7 & M_8. The entire mechanism is mounted on a piece of aluminum, UU, 1 ft square and 3/32 in thick, on which the soldered brass frame, $FFFF$, is screwed. (The diagram is a front view and the front aluminum cover above the frame, $FFFF$, is not shown in the diagram.) As can be seen with little imagination, each of the four quadrants (No. 1, for example) is held by a rod, r_1, in the middle of each adjacent side, which extends through a slot on the corresponding side of the frame, F, and is eyed to a steel wire bar, r_4, along which it is free to slide. The steel wire bar, r_4, is attached to the two inner arms of the I-shaped brass connecting rod I, on which is soldered a piece of flexible sheet brass, m. An oblong hole is cut on the end of this flexible sheet brass, m, through which the end of the vertical arm of the L-shaped crank lever L_1 is hooked, the other end being attached to the armature of the magnet M_1. The lever L_1 is pivoted through the point of intersection of the two arms to a short rod, R, attached to the end of the magnet M_1. The I-shaped connecting rod, I, slides between a common guide, G_1, and a narrow outside one, g_1. Parallel to and on either side of the rod r_1, directly attached to the shutter 1, are another two similar rods, r_2 & r_3, each being soldered on the inner ends to a common strip, t, in the middle of which a slot similar to that on the frame, F, is also cut so that the rod r_1, which connects to the shutter, will also go through it. These two rods, r_2 & r_3, being always parallel, just pass freely through two round holes on the two sides of the slot on the frame F. Two fine coil springs are wound on each of these rods, thus always keeping the metal end-strip, t, close against the side of the shutter. Since every shutter has two pairs of these spring-fitted rods that constantly exert a push on the two adjacent sides of the shutter, it is clear that the four shutters are always kept in a position forming a cross. Now supposing the armature of the magnet M_1 to be magnetized when the circuit through the magnet is closed and supposing the L-shaped lever, L_1, on this particular magnet to be in the same position as the capital letter L, it is clear that when the horizontal end is pulled by the armature of the magnet perpendicular to and away from the paper toward us, the vertical end, which is hooked to the metal strip m will turn to the right

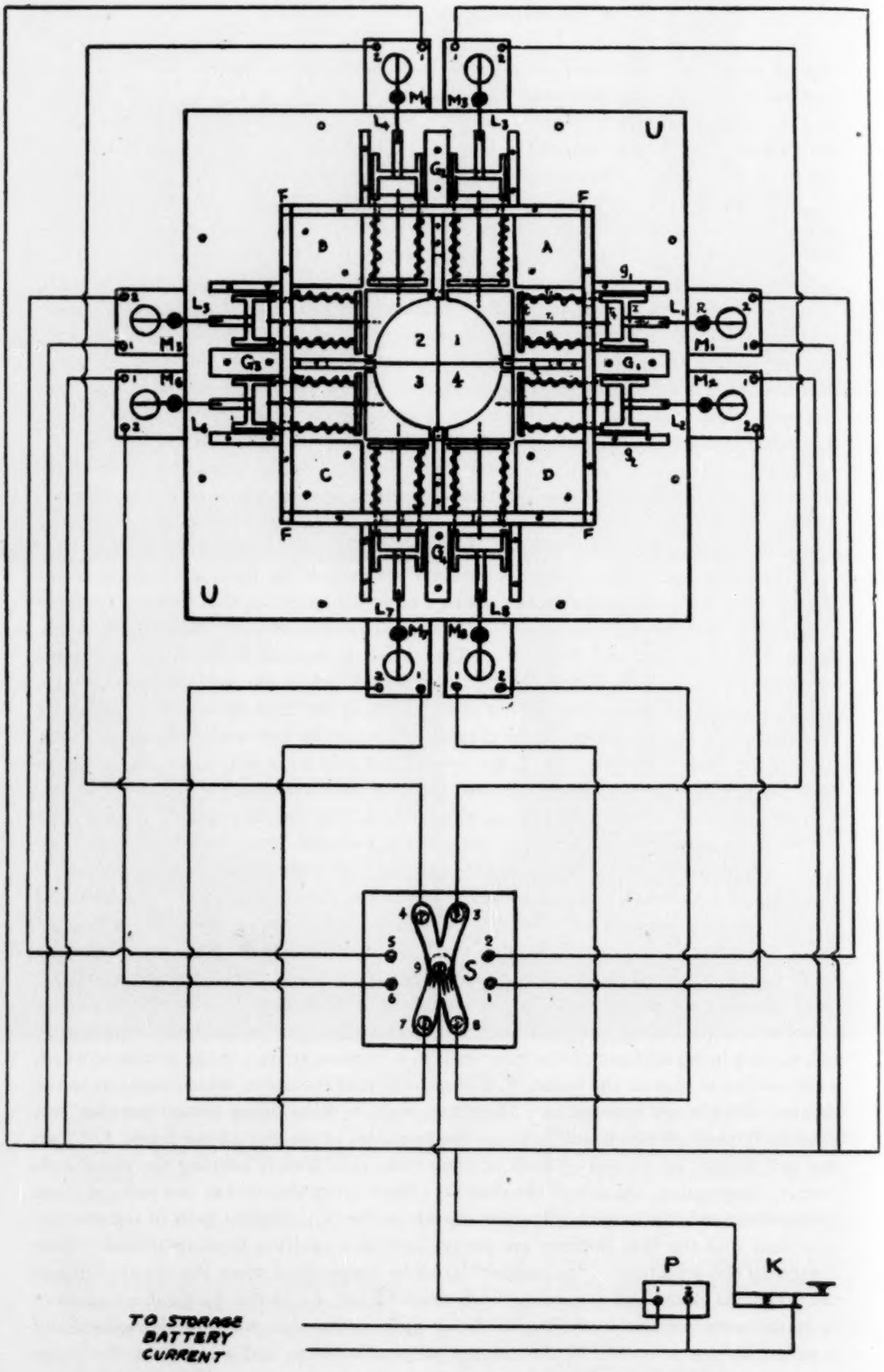

PLATE II. Quadrant tachistoscope. Shutter unit and wiring

drawing the rod r_1 with it, compressing the coil springs on rods r_2 & r_3, and hence opening the shutter 1 also to the right. Since the slots on the metal strip t and the frame F on all sides are cut to allow free play of the corresponding rods r_1 on all sides, and since the latter are eyed to the corresponding rods r_4 and free to slide along them, it is obvious that, as the shutter 1 is pulled by the magnet M_1 toward the right through the rod r_1, the other corresponding rod on the adjacent side will not hinder the motion. The corner blocks of aluminum A, B, C, & D and the brass rods g_4 serve to guide the shutters and the outer ends of the brass strips t as the shutters are opened.

The switchboard S (labeled 'D' in the views of Plate 1) has eight plugs situated exactly in the same relative positions as the eight magnets, of which the armatures of the two side pairs can be seen clearly in the back view on Plate 1. The switch arms, when placed in position as in the diagram, form an X. The outer binding posts ("2" on each magnet) are connected to the corresponding posts or plugs, 1, 2, 3, 4, 5, 6, 7, & 8, on the switchboard S, while the inner ones are connected to one another and brought to a common wire that leads to the reaction key K. The other terminal of the circuit comes from the pivot post 9 of the X-shaped switch to the auxiliary binding post 1, on P, while the other, 2, is connected to the first terminal that leads from K. As shown in the diagram, the current comes from the storage battery of ten cells (which are kept on charge at the rate of about 5 amperes, giving a voltage of about 14 volts when the apparatus is drawing current momentarily at the rate of about 15 amperes), through binding post 1 (on P), goes to the pivot post, 9, on switchboard S, and from there is divided through the four arms of the X-switch and the posts 3 & 4, 7 & 8 to the outer binding posts 2, on the corresponding magnets 3 & 4, 7 & 8; then the currents emerging from the inner posts 1, on the four magnets, after magnetizing them, meet and go through the reaction key K and binding post 2 on P, back to the battery. As it is, the upper and lower pairs of magnets are magnetized during the passage of the direct current as long as the key K is held down and consequently the upper and lower pairs of shutters open, making the exposure field a horizontal oblong (3 in $\times$ 1 in) because the circular window is 3 in. in diameter and the shutters open half-an-inch for each pair. Likewise, if we turn the four arms of the X-switch on the binding posts 1 & 2, 5 & 6, the right and left pairs of magnets will be magnetized during the passage of the current when the key K is held down and hence the right and left pairs of shutters will open, making the exposure field also an oblong (3 in $\times$ 1 in) but in the vertical direction.

The card changing and card releasing mechanism. Immediately above and below the upper and lower pairs of magnets, two specially designed card-holders, B_1 & B_2, rest on the platforms, P_1 & P_2, respectively, with guiding rails of bakelite on the two sides. The card-holder being partitioned by thin aluminum sheets into 10 compartments to the inch has a capacity of 64 cards, which are all held in the holder by a sheet-metal bottom that is free to slide back and forth between two grooves on two metal strips screwed to the bottom of the two sides of the holder. Looking from the back of the whole apparatus (Plate 1, fig. 4), we shall describe the operation of the card changing and releasing mechanism from the experimenter's position and shall take the visible end of the card-holder as its front end. To the side of the left metal strip on the bottom of each holder, B_1 & B_2, is soldered a piece of rack of a pitch of 10 to the inch, which fits to a pinion both on the top and bottom of the long brass shaft, S. Near the lower pinion and on the same shaft is screwed a ratchet of much bigger diameter. When the holders are in position (as in Fig. 4) the upper one, B_1, is loaded while the lower one, B_2, is not. As the further end of the sliding bottom of the upper holder, B_1, is hooked on the platform, P_1, cards placed in the compartments drop down through a slit on P_1, and between the two guiding strips, G_1 & G_2, to the elastic metal stopper, R, which is

attached to the upper end of the lever *L* pivoted at O. The further end of the horizontal rod *F* has two pieces of flexible brass strips, one of which turns the ratchet on the lower end of the shaft *S*, and the other pushes the lower end of the lever *L*, as we push the horizontal rod *F* at the knob. This latter flexible strip on the rod *F* is just a little bit longer than the other one that turns the ratchet on the shaft *S*, so that the lever *L* detaches the stopper *R* from the shutter unit *UU* just a second or so before the other strip turns the ratchet. Fig. 4 shows the card *C* just in the process of dropping. Now suppose that it has already dropped on the stopper, *R*, and has already been read by the subject who is on the other side of the card, at the push on the horizontal rod *F* the lower end of the lever *L* is pushed away and hence the upper end detaches the stopper *R* from the shutter unit *UU* and releases the card which immediately drops to one of the compartments on the lower holder, B_2. As soon as the card drops clear out of the way of the stopper *R* the flexible strip that pushed the lower end of the lever *L* slips off and the lever is counteracted by a coil spring behind it, thus bringing the stopper *R* back in contact with shutter unit *UU* again. Meanwhile the other flexible strip on the horizontal rod *F* works the ratchet attached to the shaft *S*, making the whole shaft turn clockwise and thereby causing both card-holders B_1 & B_2 to move out one tooth or partition. This outward movement of the upper holder, B_1, drops the next card, which is stopped by the stopper *R* again, since the latter is already held firmly against the shutter unit by the tension of the coil spring behind the lower end of the lever *L*; while the same simultaneous outward movement of the lower holder, B_2, furnishes a new vacant compartment ready to receive the card as it will drop in the next operation. The convenient card-catcher, *r*, which is bent out of a piece of copper sheet-metal in such a way that the cards may fall on it one above the other, may be used instead of the lower card-holder, B_2, in which, needless to say, the cards fall into the same relative compartments as in the upper holder, B_1, from which they drop. As the upper card-holder, B_1, is emptied, the loaded extra one, B_3, takes its place; the lower one, B_2, which has just been loaded by the cards from the upper one, B_1, is taken away with the bottom locked ready for the next use and its place is filled by B_1.

This mechanism for changing and releasing cards is, I think, new and has the advantage of such quick automatic control that an entire experiment involving 128 exposures has been completed within 25 minutes. The even rate and tempo at which the mechanism works are further advantages.

General method of operating the tachistoscope. The subject and experimenter are seated as shown in Figs. 2 and 3 of Plate 1. The experimenter, after seeing that the upper and lower card-holders are properly placed, sets the switch in the horizontal position if vertical exposure is desired and *vice versa*, and with a 1/50-sec stop-watch in hand gives the signal "Ready! Go!" and starts the watch at the instant when the subject opens the shutters by pressing the reaction key and holding it down as long as he reads. When the subject stops reading and releases the key, thus closing the shutters, the experimenter stops the watch and records the reading time in units of 1/50-sec.

Possibilities of the tachistoscope. The tachistoscope does not claim to fulfill all the requirements of a good tachistoscope in the usual sense of the word as set down by Wundt (20) and Dodge (19). The shutters open and close with considerable noise and the magnets draw a large amount of current of about 15 amperes. It was designed, however, to meet specific ex-

perimental conditions and it is different from all other tachistoscopes thus far devised and from all bradyscopes usually employed in that the duration of exposure can either be voluntarily controlled by the subject or by the experimenter or be kept constant for a certain length of time by some simple attachment. Most of the factors of legibility of Chinese characters, such as the number of strokes, nature of strokes, determining or dominating strokes, partial presentation of a character, size and style, position in group, space between characters, and unnatural positions of a character can be studied by means of this apparatus, which can also be used wherever is involved the technique of measuring reading speed under perfectly normal conditions in comparatively short units or of measuring and recording comparatively long 'judgment' or 'association' times.

Summary. (1) The term *bradyscope* (Greek, *brady*, slow; *skopein*, to view), first used by Esper, is suggested for all memory apparatus in contrast to *tachistoscope*. (2) Five types of bradyscope are recognized; the *drum*, *fall*, *disc*, *booklet* and *endless-band* types. (3) All tachistoscopes are grouped under four representative classes; Wundt *gravity*, Wirth *disc*, Dodge *mirror*, and other minor types of *spring*, *shutter*, or *pendulum* construction. (4) A new *quadrant tachistoscope* for studying the legibility of Chinese characters under perfectly normal reading conditions is described. This tachistoscope can be used either as a bradyscope or as an ordinary tachistoscope. (5) A new *card changing and card releasing* mechanism is described, which is adaptable to all exposure apparatus, bradyscope and tachistoscope alike, and which operates at the maximal speed of about five exposures to the minute.

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(Under each reference the name of the exposure apparatus is given. T denotes tachistoscope; B denotes bradyscope.)

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